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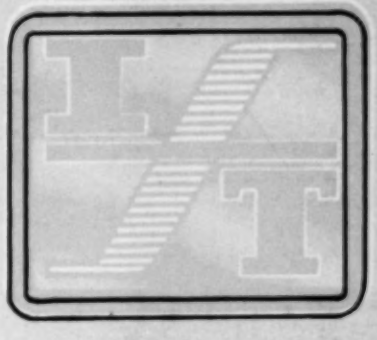

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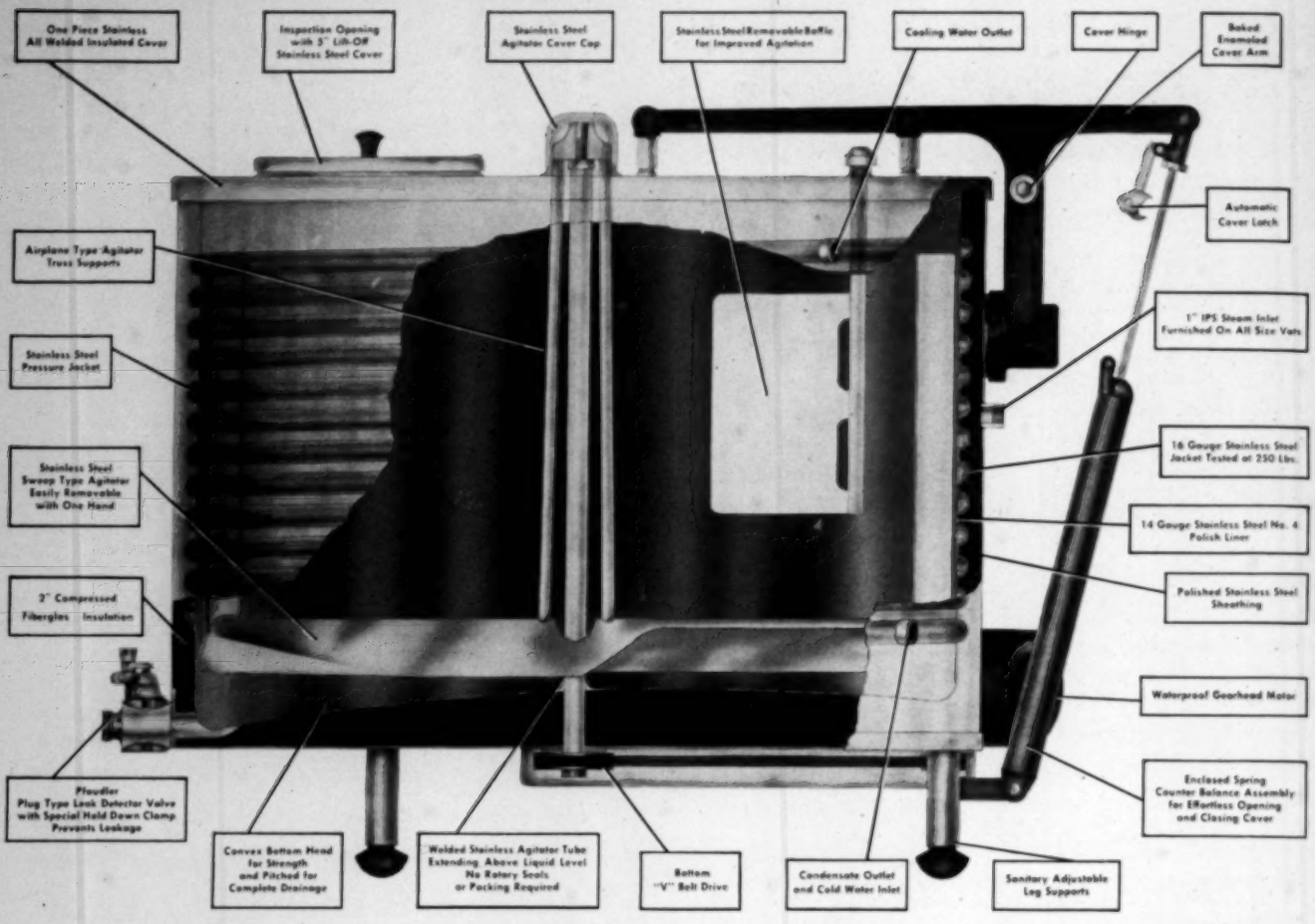
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EDITORIAL

Industrial Mobilization and Its Probable Effect Upon the Food Industry[a]

COLONEL HUGH MACKINTOSH
Quartermaster Corps, U. S. Army, Washington, D. C.

(Received for publication, May 29, 1950)

It is axiomatic that an aggressor nation resorts to war only at that time when probability appears to favor victory. Hence, we may deduce that war will come only when a potential aggressor estimates that his total strength, coupled with the advantage of surprise, gives him a reasonable expectation of success. In making such an estimate, a deficiency in one of the factors may, in some measure, be counterbalanced by an excess of the other; i.e., the potential enemy may judge that his inferiority in total strength is compensated for by his ability to achieve surprise. Our course of action, then, is clear. In order to maintain our own freedom, as well as to guarantee the freedom of peace-loving peoples everywhere, we must assure that such counterbalance is not possible. A portion of this assurance is provided by the intricate framework of national defense planning, a vital segment of which is the planning for economic mobilization in a period of national emergency. The objectives of this economic mobilization may be defined as follows:

(1) To expand economic activity to the extent that those resources which make up the nation's war potential are employed as fully as possible.

(2) To bring about such shifts or conversions within the economy as will result in the utilization of all resources for the most important uses in which they can be employed.

In order to bring into focus the specific problem of planning for mobilization of the food sector of the economy, I would first like to consider briefly the character and importance of food requirements.

Food being a necessity of life, it will be readily agreed that the production, processing, storage, and distribution of foods represent the important aspects which must be considered in the use of this vital resource, either in peacetime or war. But it does not follow that every food item is of equal importance. Nor does it mean that consumer demand for each food item represents an inflexible requirement that must be met. On the contrary, a wide range of substitutions is possible. The availability of canned or fresh foods in a particular locality may depend on whether tin plate or rail transportation is the bottleneck problem. If pressed, we can remove the luxury aspects of the diet without lowering nutritional efficiency to a significant degree. The important point is that there exists no rigid or absolute requirement as to the resources to be employed for food production in an emergency.

It would appear from these statements that we in the United States have no real concern as to the adequacy of our food supply,—that there is enough to meet our requirement. I believe that to be correct, in that our food supply is well assured with the exception of a moderate dependence on certain imports — imports which might be considered non-essential in a real crisis. In this connection, it may be of interest to mention that pepper, previously listed as an item to be stockpiled, has now been removed from that list because of our inability to prove its essentiality.

The sum total of the above is the fact that a balance in the employment of labor, utilization of our national and other resources, industrial production, professional services and military action is essential for achieving the maximum war potential. Mobilization planning must insure this balance.

Congress, recognizing the need for an agency to plan for the employment of our national resources, established the National Security Resources Board. This Board, composed of seven civilians, is charged with planning for the efficient use of our resources to satisfy both civilian and military needs in time of war. With specific regard to the food sector, some of the problems to be resolved by the Resources Board include determination of manpower to be drafted from agriculture, production and allocation of farm equipment and supplies, determination of rationing policies, price control policies, export control policies, and similar measures.

Within the Department of Defense, Congress also established the Munitions Board for the purpose of guiding and coordinating the industrial preparedness planning efforts of the military departments. For the past two years, under the guidance of this Board, the various Technical Services, Bureaus and Commands of the Army, Navy and Air Force have been engaged in detailed preparedness planning with industry. Thousands of industrial facilities have been surveyed, production schedules have been mutually agreed to by management and the defense agencies, and measures to overcome production deficiencies have been developed and implemented. In the case of non-food items, an elaborate but necessary procedure must be followed in order to accomplish these processes and to evaluate the requirements of the various military claimants for the

[a] Presented at the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 25, 1950.

production capacity of a particular facility. For food items, however, the Quartermaster Corps has been assigned single-Service purchase responsibility. With one agency, the Quartermaster Corps, thus responsible for procurement planning for subsistence for the Army, Navy and Air Force, the problem is simplified. The Munitions Board has delegated to the Quartermaster Corps full responsibility to plan for military subsistence, both with industry and the National Security Resources Board. Further simplifying planning for subsistence is the fact that the entire food-processing capacity of the country is "reserved" or "frozen." In other words, recognizing food as a necessity of life, the National Security Resources Board and the Munitions Board have ruled that food-processing capacity may not be converted to other manuafcturing processes. Within this framework, after complete coordination with the Resources Board, the Quartermaster Corps is engaged in planning for food procurement in those cases where the food items or the packaging involved are peculiar to the military and where the military requirements far exceed the normal production of industry, and problems or bottlenecks are consequently anticipated.

The Quartermaster Corps industrial mobilization staff for subsistence planning is necessarily small, and, by itself, could only scratch the surface of these problems. However, through the voluntary aid being rendered by food processors and packers, by the food processing and packaging equipment industry and by food technologists, we are beginning to make substantial progress toward the solution of problems relating to adequate wartime military subsistence. We are dependent upon industry's advice, knowledge, and experience to assure that the plans we develop will be realistic and practical.

Our initial efforts are devoted to planning for an adequate supply of specially packaged combat rations and their components, dehydrated foods and frozen boneless meats. These items, based upon preliminary studies conducted by our food specialists in conjunction with industry, appear to be the ones which may involve problems of availability.

With respect to the specially packaged combat rations, we are in the process of selecting and planning with one or more ration assemblers in each important food producing and packing area in the United States. To sasure a supply of components to each of these assemblers, we are locating and planning with individual component processors and packers. In the selection of both ration component assemblers and component suppliers, one of our principal considerations is the desirability of eliminating cross-hauling and back-hauling. Accordingly, we have "teamed up" assemblers and their components suppliers to the end that component items will flow toward assemblers, and thence, in like direction, toward the ports from which they will be shipped to our combat troops. Our design is to reduce to a minimum the "joy-riding of supplies" which occurred during World War II.

Our problem in the field of specially-packaged rations is complicated by the nature of the components. The C-4 Ration, for example, which is carried by the soldier in actual combat, consists of thirty-four different items. Among these are such integral parts as plastic spoons, chocolate and candy discs, cookies and the various individual-meal cans of meat and vegetables. These components come from widely varying types of producers, some of whom are not even in the food industry. In fact, some of the assemblers have been selected because of their packing facilities and storage space, and are not normally concerned with those types of items, both food and non-food, contained in the ration. As a result, we must aid the assembler by locating convenient and ample sources of components. In addition, we must further aid him by scheduling deliveries which will be adequate to insure a continuous assembly and packaging operation, yet avoid overflow of his available storage space. During World War II, one assembler's receipt of halazone tablets (included in the ration to permit water purification by the individual soldier) was temporarily interrupted. While he strove frantically to restore the flow of these tiny bottles of tablets, his receipt of other components continued, with the result that his warehouses bulged with components and partially completed ration assemblies.

Any study of logistics tends toward the inevitable conclusion that the "pounds per man per day" required to equip and sustain the combat soldier will increase progressively with the development of new forms of warfare. Since this progression must be supported by additional shipping facilities, defense facilities, and manpower for handling, it follows that the progression is geometric in nature. In an effort to reverse this trend, the utilization of dehydrated foods by the combat soldier was initiated in World War II. In one year it was estimated that the net saving in shipping space resulting from the use of dehydrated foods amounted to 257 ship loads of the 10,000-ton class. In that same year, the net saving in tin plate resulting from the use of dehydrated instead of conventionally canned foods amounted to approximately 109,000 tons, while the net saving of pig tin was 1,100 tons.

The above statistics can be measured. But it is not possible to measure the savings to the over-all war effort resulting from reduced need for destroyer convoys or anti-aircraft guns to protect truck or rail trains, or for line-of-communication troops to guard shipments. Nor is it possible to measure the saving in manpower for handling from the dehydrator to the combat soldier. Less fuel was also required for ships, vehicles and trains, while fewer freight cars and vehicles were required in the movement of dehydrated foods.

The dehydrated foods industry expanded greatly during World War II in order to meet the needs of the Armed Forces, to supply civilian needs, and to help feed our allies and the populations of both liberated and occupied areas. Techniques had to be developed as the industry strove to meet requirements. It is reasonable to assume that the palatability of dehydrated foods was often adversely affected by either lack of proper dehydrating equipment, incompletely developed dehydrating techniques, or improper handling in processing. Since

the war, many dehydrating facilities have shut down, and, of these, a number have been dismantled. Neither the necessary equipment nor the skilled personnel are readily available for another emergency. Preliminary estimates indicate that the available capacity will fall far short of meeting wartime needs, and we are studying those measures which should be initiated now in order to expedite expansion of this segment of the food industry. We are surveying the availability of dehydrating facilities, and through the medium of industrial preparedness planning studies, hope to develop detailed data which will permit rapid expansion of the existing capacity.

In this field, the members of the Institute of Food Technologists can be of inestimable assistance. In addition to the direct aid which they can give in the development of our planning, they can effect a secondary, and virtually as important advance in degree of readiness. This is through the development of improved dehydrating techniques for the production of more palatable foods at reduced processing cost. The anticipated resultant increase in consumer acceptance of dehydrated food items will result, in turn, in the peacetime expansion of the industry, thus increasing the production potential available to meet any emergency.

In addition to the necessity for planning for the assembly of special rations, and for the production of dehydrated foods, we must also consider special equipment and processes which are more or less peculiar to military subsistence. Among these, the most important are procoating, closure equipment for the special small-size cans required for individual combat rations, and equipment for the production of compressed food items such as cereal and cocoa discs.

Procoating,—the application of a protective coating to filled cans,—serves both to protect the exterior of the can against abrasion and deterioration, and to camouflage the can. Our requirements for procoated canned foods appear to represent a serious delay in the receipt of these items. Only a handful of World War II suppliers still possess procoating equipment, or even the necessary "know-how." Little or no production in this field can be anticipated during an early period of mobilization when additional equipment is being manufactured and processors are working out production techniques. In addition, off-shore fish canneries; the food canneries; producers of bakery, cereal, dairy, and meat products; all report no room in their plants for an operation such as procoating, particularly in view of the penetrating odor which results. This problem has recently become the subject of a Quartermaster Corps research and development project intended to develop an improved process or technique.

I have tried to describe some of the more important of our presently visualized problems in the field of wartime subsistence. However, it must be emphasized that the Quartermaster Corps is concerned with planning for but a limited portion of the over-all food industry. We are in no position to comment upon the potential wartime needs for additional food processing and packaging equipment for the industry as a whole. In a related sense, we cannot begin to estimate the effect of the possible conversion of food machinery production facilities to the manufacture of military equipment. Also beyond the scope of our plans—indeed, of our capabilities—is an estimate of the need and availability during wartime of certain common components of food processing machinery, such as electric motors, etc.

While such problems are beyond the scope of our studies, the National Security Resources Board is actively interested in these matters, and is studying them through the medium of task groups composed of members of the food industry. The industry itself knows that most of its key equipment require critical materials and components,—stainless steel, aluminum, electric motors, and the like. Also it best appreciates its problems of equipment, maintenance and repair. We urge the industry to take steps to insure that the appropriate task groups of the National Security Resources Board have such matters on record and plans available in anticipation of the needs of the food industry in these areas.

Since the early days of our Republic, men have been willing to work and fight and die in the defense of our liberties. In wartime, both industry and science have worked unsparingly,—often without compensation or desire for gain,—in order that we might be victorious. It is a more difficult thing to work in time of peace to insure that our Nation will continue to be free. But the urgent necessity for this work is only too apparent. No longer may we expect time to be on our side in the event of a crisis. No longer can we rely on powerful allies to stave off the enemy's attack until we are ready. No longer can we be assured of invulnerability from attack by air or by sea. The time for such work is now.

The assistance given the Quartermaster Corps by the food processing industry, food equipment manufacturers, and food technologists has been, and we are certain will continue to be, a deciding factor in the speedy solution of our problems. Such cooperation is greatly appreciated, and we hope will not only continue to be offered but extended to the maximum in the interest of national security.

Food Technology Curricula

This is the fifth of a series of articles which are intended to elucidate the basic ideas that govern the curricula of our educational institutions in the field of food technology. The four previous articles described the curricula at some of our leading educational institutions and further articles of the same sort will be printed in subsequent issues of FOOD TECHNOLOGY. *The present discussion deals with an analysis of some of the trends in technological education and is printed here in order to broaden the general appreciation of the reasoning behind the establishment of curricula in technological education.*

Modern Trends In Technological Education[a]

HENRY T. HEALD

Illinois Institute of Technology, Chicago, Illinois

It is no accident that the United States in the past half century has attained the highest standard of living ever reached in the recorded history of man. A private competitive system of doing business coupled with an amazing record of accomplishment in science, engineering, and technology has enabled us to reach a peak in the production of goods and services which would have been considered fantastic by our grandfathers.

This is the day of the implemented idea, of organized group thinking which pushes back the frontiers of the physical sciences, finds new knowledge, and then applies it rapidly and effectively to the engineering problems which confront industry.

Farsighted companies whose managers are always on the alert for new ideas, new inventions, new applications of scientific principles are the ones that will produce the new products of tomorrow. Those whose management is satisfied with the scientific status quo will surely lose their leadership and gradually cease to exist.

Alert industrial management, therefore, is more than a little concerned with the methods and the product of institutions of higher education — particularly those which emphasize technological education—because out of the classrooms of today come the men who will decide the course of tomorrow's progress.

Enrollment in engineering colleges swelled after the war, and this year's graduates numbered more than in any other year in history. Although it appears that temporarily the supply has exceeded the demand, next year the supply will more nearly equal demand, and by 1952 the supply situation will begin to reverse itself quickly. The present number of freshmen and sophomores in engineering colleges is nearly at pre-war levels; and, since engineering is a rapidly expanding profession, there is every indication that after 1952 there will probably be a shortage of engineering graduates.

Engineers fill a multitude of positions in our business and industrial system. Their initial and primary role is in research, development, design, construction, production, operation, and maintenance. Many find their interests lie in the specialized areas of purchasing, transportation, distribution, or sales. And not a few find their way into administration and management. Engineers have from 10 to 20 times the probability of attaining executive positions as compared with other college graduates.

In addition to his courses in science, engineering, and technology, the engineering student should have a reasonably broad background in the social sciences and humanities, such as economics, English, history, political science, and industrial, personnel, and public relations. These subjects are necessary to provide the broad background essential for administrative and managerial work.

There has been a tendency among engineering educators in the past to overload engineering curricula with strictly engineering subjects; that is, to stress the scientific-technological stem at the expense of, and sometimes almost to the exclusion of, the social-humanistic stem. There also has been a tendency to pile course upon course until the student was burdened with more hours of study than he could possibly handle during four years of college attendance.

The trend now, however, is toward less specialization because highly specialized training for a specific industry can best be provided on the job. The education of an engineer consists, first, of a thorough preparation in the basic sciences; next, he is taught the engineering applications of these fundamental laws, and finally he takes courses in a particular field of specialization.

Although we educate engineers as specialists, we must also educate them as citizens who, to contribute their maximum potential to the society in which they live and make a living, must understand the social, political, and economic problems of our time. Unless they do understand these problems which beset us, and unless they actively participate in their solution, our country is harmed and not helped by our educational system. While we strive to provide professional competence, we must also seek to instill social consciousness, personal integrity, and moral responsibility in our students.

Unprecedented enrollments in under-graduate curricula in post-war years have been accompanied by a similar surge of interest in post-graduate enrollment. Since the first World War, there has been a gradual expansion in graduate work in engineering and technology. World War II, with its tremendous engineering accomplishments, provided a terrific impetus for graduate education. There is an increasing demand for men trained beyond the conventional boundaries of undergraduate instruction.

To a greater degree and over a wider range than ever before, industry is dealing with problems at the border of our knowledge of engineering applications. Scientific principles are being put to use to accomplish old results

[a] Condensed from a paper read at the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 22, 1950.

in new ways or develop new areas of application. Since undergraduate programs do not reach the new areas of activity, additional training in the form of graduate work is aimed to prepare men "to push back the frontiers of science." It is quite safe to predict that graduate programs will continue to increase in number and scope.

Here, then, are some of the trends in modern technological education—in enrollment, in curricula, and in graduate education. All of these are extremely important to industry, because no two groups on the American scene are more closely allied or more dependent upon each other than industry and education. This inter-dependence has been widely accepted and fostered as an idea, but only partially implemented. Education has furnished in increasingly large numbers the trained personnel needed by industry for integration in its total manpower picture, but industry has not supplied in sufficient amounts the financial resources needed by education to do the job.

Government has filled the void left by industry's reluctance to support education and research on the scale necessary to keep pace with society's demands. Our educational system has traditionally been a balance between state- or tax-supported institutions, on the one hand, and privately-supported colleges and universities, on the other. Each has provided a check on the other; each has been a stimulus to the other; together they have made major contributions to the nation's economy and culture.

If privately-supported education is forced to relinquish its influence because of apathy toward its needs, the nation will surely be the loser. If industry and business are loathe to provide the financial assistance so sorely needed by private education, then government will supply the funds,—and exert its inevitable control; for the holder of the purse insists on saying where the money goes and what it buys. And this applies to ideologies, as well as to the material ingredients required in the eductional process.

Prevention of Sucrose Hydrate Formation in Cold Processed Frozen Fruit Spreads[a]

J. E. BREKKE AND WILLIAM F. TALBURT
Western Regional Research Laboratory,[b] Albany, Calif.

(Received for publication, June 27, 1950)

Three methods for the prevention of sucrose hydrate formation in frozen fruit products were studied: control of storage temperature, hermetic sealing, and use of invert sugar as part of total sugar added. The latter two methods appear to be effective. Storage at —10° F. (—23.3° C.) appears to be more favorable for hydrate formation than either lower or higher temperatures.

Cold-processed frozen fruit spreads are jelly-like products which possess the flavor and aroma of fresh fruit because they are prepared without the use of heat. They contain, in addition to fresh or frozen fruit puree or juice, small amounts of citric acid, about 0.5 percent of rapid set pectin (dispersed without the use of heat), and enough added sucrose to bring the soluble solids content to 57 percent. They must be kept in refrigerated storage and, like other frozen fruit products of high sucrose content, are subject to formation of crystalline deposits of sucrose hydrates.

Such crystalline deposits cause deterioration in the appearance and the texture of frozen fruit spreads. Sucrose hydrates first appear as white, moldlike, spherulitic formations at the surface of the product, slowly increase in magnitude during freezing storage, and eventually involve the entire mass of the product. Some of the sucrose in these products can be replaced by glucose or by invert sugar, but if too much glucose is used, glucose hydrate appears as white, bead-like deposits throughout the mass after it has been stored for some time. The sucrose hydrates encountered in this work melted quickly at room temperature, and hence were less troublesome than glucose hydrate, which persisted even after the product was warmed to room temperature.

The prevention of such hydrate formations in cold-processed frozen fruit spreads has been studied in relation to (a) the substitution of varying amounts of invert sugar and of glucose for sucrose, (b) the effects of storage temperatures, and (c) the use of hermetic and of non-hermetic containers.

Joslyn *(4)* reported the appearance of white, gummy deposits in fruit sirup packs. Later he noted *(5)* that sirups containing very much dextrose "developed waxy crystals" of this sugar. A fondant-like mass in frozen fruit packs was described by Rabak and Diehl *(7)* as having a mold-like appearance. They determined the composition of the material as being 82.3 percent sucrose, 4.71 percent glucose, and the balance water. Loeffler *(6)* stated that a "fondant" appeared in frozen raspberries packed 3 plus 1 with 68 percent sucrose sirup, Cruess *(2)* described the separation of "sugary solids" from samples of fruit packed with various amounts of dextrose. Young and Jones *(9)* of this Laboratory have described a number of sucrose hydrates which crystallize from sucrose solutions at low temperatures. They noted that the mold-like crystal growths in frozen fruits packed with added sucrose are sucrose hydrates and identified one hydrate found in frozen fruit

[a] Presented before the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 24, 1950.

[b] Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

as the hemiheptahydrate of sucrose. They suggest the possibility that other hydrates may occur in other samples. The properties of glucose hydrate have been described by Bates *(1)* and by Winchell *(8)*.

Preparation of Samples

The method of preparation of cold-processed frozen fruit spread (cold-processed gel) has been described by Johnson and Boggs *(3)*. It consists essentially of mixing fruit puree, citric acid, pectin, and sugar. The starting material used in this work was frozen puree of Lassen strawberries which contained 6 percent soluble solids. The puree (pH 3.4) was first acidified by adding citric acid until the pH had been lowered to 3.0. Then sucrose was added to bring the soluble solids up to 57 percent, and enough pectin (150 grade, rapid set) to increase the pectin content of the final product by 0.56 percent. When studying effects of the substitution of varying amounts of other sugars for the sucrose in the formula, glucose was added as the granular glucose monohydrate commonly used in the industry, and the invert sugar used was a product of acid inversion containing 77 percent soluble solids. After thorough mixing of the ingredients, the gel mixes were poured into the containers and allowed to stand at room temperature for 24 hours for gelation to take place before being placed in freezing storage. The following percentages and kinds of sugar were added to each of the nine batches prepared.

Sample number	1	2	3	4	5	6	7	8	9
Sucrose, percent	100	90	80	70	50	90	80	70	50
Glucose, percent	0	10	20	30	50	0	0	0	0
Invert sugar, percent	0	0	0	0	0	10	20	30	50

Samples from each of the 9 batches were packaged in waxed paper cups with press-on lids, in 4-oz. jars with rubber-gasketed screw-on lids, and in 211 x 200 sanitary tin cans. Aliquot lots of each batch and each container type were placed in storage at —30°, —10°, 0°, and + 10° F. (—34.4°, —23.3°, 17.8° and 12.2° C., respectively.) After two days' storage, half of each lot of samples in hermetically sealed glass jars were opened and a small mass of crystals of sucrose hemiheptahydrate was placed on the surface of each gel; these seeded samples were then re-sealed. The samples in cups were not seeded. The samples in jars and cups were examined first at intervals of one week and later at intervals of 2 weeks or one month during a year of storage. One set of samples in sanitary cans was opened after one month of storage, one after 6 months, 9 months, and 12 months. The occurrence and quantities of sucrose and/or glucose hydrates were noted.

Effect of Composition

The seeded samples in jars and the samples in cups demonstrate the effects of sugar composition and storage temperature on formation of sucrose hydrates. Table 1 lists the storage time in weeks before sucrose hydrates appeared in seeded samples stored in jars. It is apparent that 30 percent substitution of invert sugar for sucrose is the most effective of the sugar-replacement formulas tried.

Table 2 gives the relative amounts of hydrates present in the seeded samples stored in glass jars. After one year of storage, all samples in which 30 percent of the normal sucrose requirement had been added as invert sugar were free of sucrose or glucose hydrates except those stored at —10° F., and only a trace of sucrose hydrate was apparent on them. The samples containing 50 percent sucrose and 50 percent invert sugar and stored at —10°, 0°, and + 10° F. showed traces of glucose hydrate at the surface. Glucose hydrate involved the entire mass of the gels in samples 4 and 5 (containing 30 and 50 percent glucose, respectively), except for sample 4 stored at —30° F. As can be seen in Tables 1 and 3, samples stored in paper cups exhibited the same trend as the seeded samples in jars. Here again, sample 8 containing 30 percent invert sugar and stored at —10° F. showed only traces of sucrose hydrates, and no glucose hydrate.

TABLE 1

Time of First Appearance of Sucrose Hydrates in Seeded Cold-Processed Fruit Spreads Stored in Jars

Percent replacement of sucrose with other sugar	Storage temperature			
	—30° F.	—10° F.	0° F.	+10° F.
	Weeks of storage			
0 percent glucose	45	2	1	3
10 percent glucose	45	1	1	>52
20 percent glucose	45	2	3	>52
30 percent glucose	45	5 [a]	8 [a]	8 [a]
50 percent glucose	45 [a]	4 [a]	2 [a]	3 [a]
10 percent invert sugar	45	2	1	>52
20 percent invert sugar	45	2	6	>52
30 percent invert sugar	>52	10	>52	>52
50 percent invert sugar	>52	37 [a]	45 [a]	52 [a]

[a] Glucose hydrate.

TABLE 2

Amounts of Sucrose Hydrates Apparent in Seeded Cold-Processed Fruit Spreads Stored in Jars for One Year

Percent replacement of sucrose with other sugar	Storage temperature			
	—30° F.	—10° F.	0° F.	+10° F.
	Percent of fruit spread volume involved			
0 percent glucose	trace	100	100	100
10 percent glucose	trace	100	80	0
20 percent glucose	trace	90	3	0
30 percent glucose	trace [a]	100 [a]	100 [a]	100 [a]
50 percent glucose	100 [a]	100 [a]	100 [a]	100 [a]
10 percent invert sugar	trace	100	10	0
20 percent invert sugar	trace	50	1	0
30 percent invert sugar	0	trace	0	0
50 percent invert sugar	0	trace [a]	trace [a]	trace [a]

[a] Glucose hydrate.

TABLE 3

Time of First Appearance of Sucrose Hydrates in Non-Seeded Cold-Processed Fruit Spreads Stored in Paper Cups

Percent replacement of sucrose with other sugar	Storage temperature			
	—30° F.	—10° F.	0° F.	+10° F.
	Weeks of storage			
0 percent glucose	52	8	8	18
10 percent glucose	>52	8	12	37
20 percent glucose	>52	8	12	45
30 percent glucose	>52	12 [a]	8 [a]	12 [a]
50 percent glucose	45 [a]	8 [a]	8 [a]	8 [a]
10 percent invert sugar	>52	12	12	37
20 percent invert sugar	>52	12	52	45
30 percent invert sugar	>52	37	>52	>52
50 percent invert sugar	>52	45	37 [a]	45 [a]

[a] Glucose hydrate.

Effect of Container

It was found that unseeded gels packed in hermetically sealed containers (jars or cans) did not show

sucrose hydrate formation. The hydrates appeared only in the paper cups and in samples packed in jars and seeded with sucrose hydrate crystals. Figure 1 shows a complete set of gels (nine sugar ratios and four storage temperatures) that have been stored for one year in sanitary cans. They are free of any visible evidence of sucrose hydrate. Glucose hydrate formed in samples 4 and 5, which contained 30 and 50 percent glucose, respectively, at all temperatures except —30° F. Glucose hydrate did not separate in samples which contained 20 percent or less of the added sugar as glucose, but in such samples the glucose was not effective in preventing sucrose hydrate formation, provided other conditions

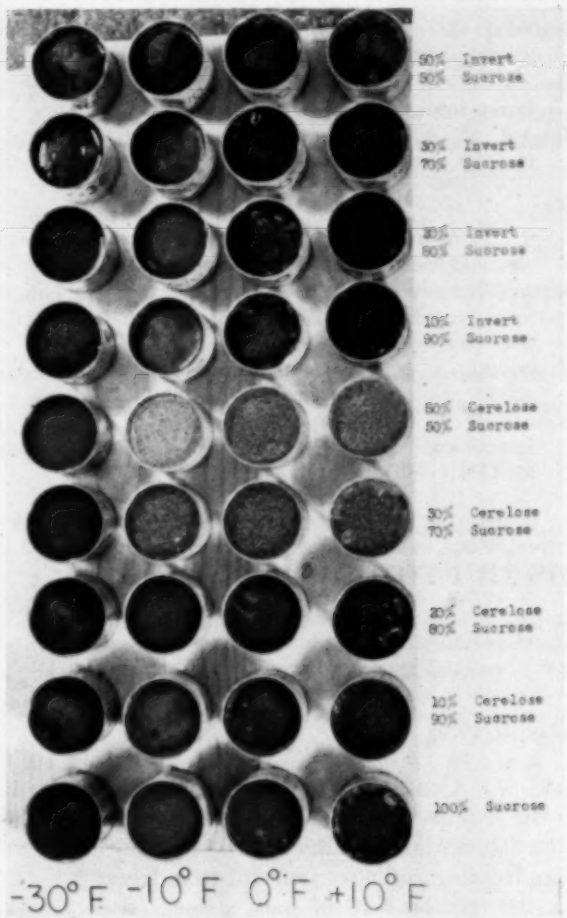

FIG. 1. Cold Processed Fruit Spreads With Various Added Sugars After One Year of Storage in Hermetic Containers.

were favorable. The glucose hydrate took the form of waxy white spheres suggestive of white caviar; it persisted at room temperature. Results in unseeded jars duplicated those for the cans. Figure 2 shows a complete set of gels in cups after 45 weeks' storage. This non-hermetic container permitted the growth of sucrose hydrates on all samples in which other conditions were suitable, but the hydrates did not appear as rapidly in the cups as in the seeded samples stored in jars.

Effect of Storage Temperature

The temperature at which least hydrate appeared was —30°, next was +10°, then 0°, and most appeared at —10° F. Under these conditions it appears that tem-

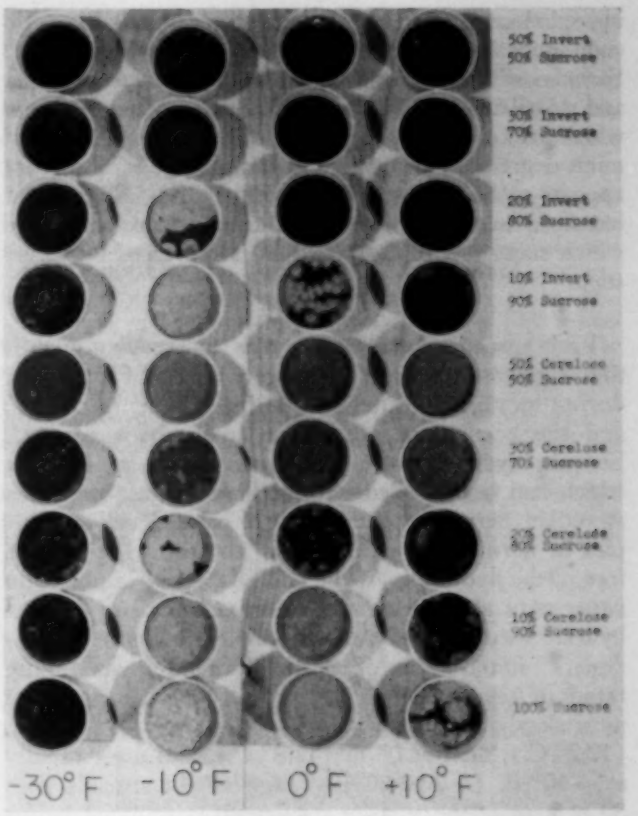

FIG. 2. Cold Processed Fruit Spreads With Various Added Sugars After One Year of Storage in Non-Hermetic Containers.

peratures in the vicinity of —10° favor most rapid growth of sucrose hydrate crystals. Any change in the physical conformation of the mass, such as formation of crystalline spherulites, would be slowest at —30°, where the viscosity is highest. At —30°, samples showed a white opacity (indicative of the presence of ice crystals) which partially masked the red color of the fruit. No such opacity was observed at the other three temperatures.

Discussion

The results of these experiments indicate that the difficulties caused by sucrose hydrate in cold processed gels can be overcome by proper selection of sugars, container, or storage temperature. Rapid flavor deterioration at +10° F. storage, and the costliness of —30° F. storage eliminate these temperatures. When non-hermetic containers are used, storage at —10° F. allows the formation of sucrose hydrates to proceed rapidly at that temperature.

The role of hermetically sealed containers in preventing sucrose hydrate formation in these experiments is not understood. Perhaps the hermetic seal prevents entry of microscopic crystals of sucrose hydrate that could act as seeds to initiate crystallization. The hermetic seal also prevents escape of water vapor and consequent desiccation and increase in sucrose concentration on the surface layer which might hasten the onset of crystallization.

The addition of invert sugar to replace 30 percent of added sucrose was quite effective in preventing sucrose hydrate formation, although trace amounts did appear

in seeded samples and in samples stored in non-hermetic containers at —10° F. over the one-year storage period. Samples with 50 percent of the required sugar as invert and stored at —10° F. showed traces of glucose hydrate, which makes this composition undesirable. The optimum degree of substitution of invert sugar for sucrose appears to be between 30 and 50 percent. No attempt has been made to determine the exact mechanism by which sucrose hydrate formation is repressed by invert sugar.

Summary

Fruit spreads containing sucrose and varying quantities of glucose or invert sugar were observed for a year during storage at different sub-freezing temperatures, and the occurrence of sucrose hydrates was noted. Sucrose hydrates were found in one set of samples which had been seeded with sucrose hydrate and then stored in hermetic containers. A parallel set of samples in hermetic containers, but not seeded, remained free of the hydrates. At the end of the year, samples in paper cups showed about the same amount of sucrose hydrate formation as seeded samples in hermetic containers; initial rates of crystal formation were more rapid in seeded samples. Sucrose hydrates appeared most slowly at —30° F. (—34.4° C.), next at +10° F. (12.2° C.), next at 0° F. (17.8° C.), and most rapidly at —10° F. (—23.3° C.) storage. Fruit spreads with 30 percent of the sucrose requirements replaced by invert sugar showed only a very slight growth of sucrose hydrate crystals.

Acknowledgments

The authors wish to thank Frank E. Young and Francis T. Jones of the Physicochemical and Analytical Division of this Laboratory for crystals of sucrose hemiheptahydrate used for seeding samples and for their help in microscopic identification of various hydrates.

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Survival of Microorganisms In Frozen Meat[a]

WILLIAM L. SULZBACHER

Bureau of Animal Industry, Agricultural Research Administration, U. S. Department of Agriculture, Beltsville, Maryland

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A comparison was made of the numbers of various groups of microorganisms surviving in frozen pork, packaged in various ways, after 12 weeks' storage at 0° F. (—18° C.) and 25° F. (—4° C.), with the numbers of organisms in the fresh, unfrozen meat. Psychrophilic bacteria were isolated from both frozen lamb and frozen pork and a study of their cultural characteristics and temperature reactions was made.

The tremendous increase in the popularity of frozen foods during the past two decades has occasioned considerable interest on the part of research workers in the growth and survival of microorganisms in foods during freezing and freezer storage. A considerable number of investigations are recorded in the literature dealing with the numbers of microorganisms in various frozen dairy products, fruits, vegetables, and fish. Much of the earlier literature dealt with the survival and toxin development of *Clostridium botulinum* and other pathogens. This work has been effectively summarized by Prescott and Tanner *(11)* and, more recently, by Fitzgerald *(4)*. Consequently it is now generally recognized that the sanitary quality of frozen foods depends largely on the manner and rapidity with which they are handled before freezing and after removal from freezer storage.

In the specific field of meat preservation, however, there is a far less extensive literature to guide the research worker. Here we are concerned not only with the possible survival of pathogenic and toxigenic bacteria but also with the survival and growth of all saprophytic organisms that might play a part in the deterioration of the product. The numbers of organisms are of interest, but so is a knowledge of the specific forms likely to be encountered. In this connection Haines *(7)* recognized that the growth of *Pseudomonas* species at subfreezing temperature was likely to play a part in meat spoilage. Greer, Murray and Smith *(5)* noted that the bacterial content of hamburger steak showed an overall reduction of 84 percent after freezing and storing at 0° F. (—18° C.) for 1 month. Proctor and Phillips *(12)* reported some rather high counts in frozen pre-cooked meat products but also observed a marked decrease in the counts during freezer storage.

[a] Presented before the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 24, 1950.

In general the observation of a rapid reduction in bacterial population during freezer storage agrees with most of the work reported in the literature on frozen fruits and vegetables. However, not all workers are in agreement. Thus Johns and Berard *(10)* reported that although they observed an immediate reduction in the number of organisms in egg melange on freezing, subsequent storage for 6 months at 5° F. (—15° C.) did not affect the number of bacteria present, except the coliform organisms, which died off in 3 months or less. Also Weinzirl and Gerdeman *(14)*, Ellenberger *(3)*, and others reported increases in the number of bacteria in ice cream during freezer storage. Weinzirl and Newton *(15)* noted that of ten hamburger samples averaging over 200 million organisms per gram, six were reduced to 10 million organisms per gram in one year's storage at 14° F. (—10° C.).

The present paper is a report of the bacteriological findings in a larger study designed primarily to compare certain methods of protecting meat during freezer storage. In order to accelerate the deteriorative changes being studied, meat was stored at 25° F. (—4° C.) as well as at the more usual temperature of 0° F. (—18° C.). This made it possible to obtain data which contrast the survival of microorganisms in frozen meat stored at an adequately low temperature with that at a questionably high temperature. The cultural characteristics and taxonomy of the psychrophilic organisms isolated were also studied.

Experimental Methods

The meat used in studies on frozen pork consisted of loins from hogs weighing approximately 225 pounds and of uniform feeding that had been produced at Beltsville in record-of-performance studies. The loins were cut into pieces about 6 inches long and distributed into lots according to a statistical plan so as to minimize the effects of any individual animal. One lot of the loin samples was frozen and stored without further treatment. One lot was wrapped in high grade cellophane, and one was boned and placed in 307 x 400 size tinplate cans which were sealed under 28 inches of vacuum. The cellophane-wrapped and vacuum-canned samples were placed in the freezer as soon after sealing as possible.

Sampling for bacteriological analysis consisted of opening the can or cellophane package with the usual aseptic precautions and removing a slice 1 inch thick from one end of the piece of loin. In the unfrozen control samples this was done with a sterile knife but in sampling the frozen meat the slice was sawed off with a butcher's saw, the blade of which had been sterilized by autoclaving. During these operations the meat was handled on a small wooden cutting board that had been cleaned with soapy water and phenol and then well rinsed with boiling water. Fifty g. of meat was then placed in a sterile Waring Blendor jar, 150 g. of sterile physiological salt solution added, and the mixture blended for 90 sec. This original 1 to 4 dilution was further diluted for plate counts in the usual manner. Each dilution was poured in triplicate and counts were recorded as the logarithmic average of the number of organisms per g. of meat. Six samples were used to represent each type of protection and temperature of storage.

In subdividing the original slice with sterile scalpel and forceps to obtain the 50 g. portion for blending, care was taken to include only about half as much fat as lean tissue and the original slice was always cut perpendicularly to the old exposed surface of the loin. In this way the relationships between bacteria recovered from the surface and the deep tissue, and from lean meat and fat, were held constant insofar as possible. The counts reported, therefore, represent a composite average of both surface and subsurface flora.

Plate counts were determined on agar prepared with Difco veal infusion medium to which was added 0.5 percent salt and 1.5 percent bacto agar. Plates were incubated at 99° F. (37° C.) and 68° F. (20° C.) for aerobic counts and at 99° F. (37° C.) in a Brewer or Spaulding jar for anaerobic counts.

Coliform organisms were determined by inoculating lactose tubes with decimal quantities according to the Most Probable Number technique *(8)*. Positive lactose fermentations were confirmed by streaking on eosin methylene blue agar and only confirmed tubes were finally considered positive.

Lipase-forming organisms were determined by plate counts using a modification of the Jensen-Turner method *(9)*. The medium used was made as follows: To 250 ml. of the veal infusion agar described above 2.5 g. of lard and 37 ml. of a freshly filtered 0.1 percent aqueous solution of Nile blue A were added. The mixture was autoclaved and while still hot was mixed for 1 min. in a Waring Blendor. The agar was poured directly from the blendor jar as soon as it was sufficiently cool and the plates were incubated at 68° F. (20° C.). The appearance of colonies is the same as that described by Jensen *(9)*.

Bacteria were isolated from slime on frozen lamb legs by removing portions of the slime with sterile swabs. The swabs were placed in tubes of dextrose broth and plates were poured from this broth immediately, and after 24 hours incubation at 25° F. (—4° C.). The plates were incubated at 25° F. (—4° C.) and 68° F. (20° C.) and colonies from plates at both temperatures were transferred to agar slants for further study.

Results and Discussion

Figure 1 shows the counts made at 99° F. (37° C.) on the frozen pork loin compared with the average counts on six fresh unfrozen samples. The control samples were treated exactly the same as the stored samples (i.e., wrapped, canned, or unprotected) but were taken to the laboratory for analysis at the time when the others were placed in the freezers. The counts were not particularly high in any instance and all the stored samples had slightly fewer 99° F. (37° C). aerobes than the control. Furthermore, there was very little difference between the counts on the meat stored at 0° F. (—18° C.) and that stored at 25° F. (—4° C.). Obviously there was no growth during storage of these mesophilic organisms and all those recoverable from the stored samples must have been present in the original meat.

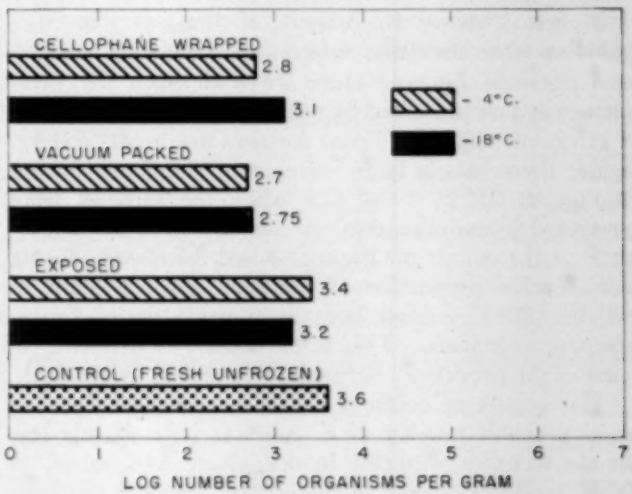

FIG. 1. Number of aerobic organisms in frozen pork after 12 weeks storage counted at 37° C.

Figure 2 is a similar comparison of bacteria growing at 68° F. (20° C.), an incubation temperature that is favorable to a large group of mesophilic organisms unable to grow well at 99° F. (37° C.), and also to the true psychrophils. Here we note that, in direct contrast to the counts of 99° F. (37° C.) aerobes, all the stored samples had higher counts than the control. In the exposed samples there was little difference in the counts on meat from the two storage temperatures, but when

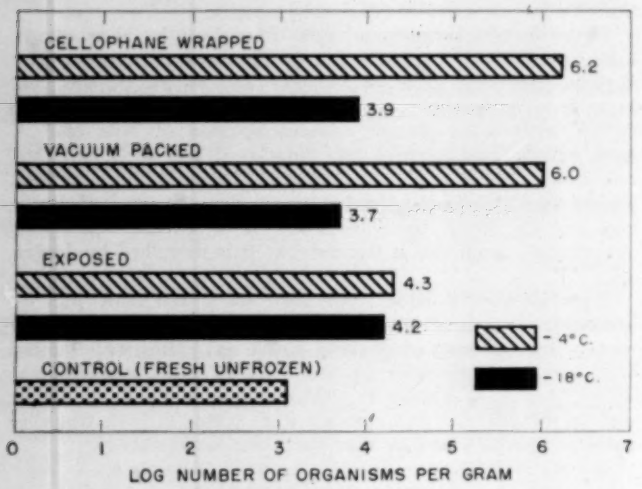

FIG. 2. Number of aerobic organisms in frozen pork after 12 weeks storage counted at 20° C.

the meat and the bacteria as well were protected from the effects of desiccation considerable growth occurred at the higher storage temperature. Even the samples stored at 0° F. (—18° C.) showed a small but definite increase. Since it is highly improbable that any actual growth occurred at this temperature, the increased count must represent a combination of experimental variables and growth that took place during the cooling period, after the samples were placed in the freezer. This hypothesis is supported to some extent by the fact that there is only a small difference in the counts of the samples stored at 0° F. (—18° C.) with respect to type of protection and that the lowest count was obtained from the vacuum-packed samples where oxygen was a limiting factor.

Figure 3 shows the counts of lipase-forming organisms from the same samples as were used for the two previous figures. Here we find much the same picture as that presented by the 68° F. (20° C.) aerobes, a group of which the lipase formers are a part. Here, again, there was a large increase in the count during storage at 25° F. (—4° C.) when the samples were protected from desiccation. A comparison of the magnitude of the counts on Figures 2 and 3 indicates that a considerable proportion of the total aerobic count at 68° F. (20° C.) must have been made up of lipase-forming organisms. This is particularly interesting in view of the prevalence of rancidity in stored frozen pork.

The counts of coliform organisms showed that the most probable number of *E. coli* was only slightly less in the samples wrapped in cellophane and stored at 0° F. (—18° C.) than in the control and had not been reduced in the vacuum-packed samples at that tem-

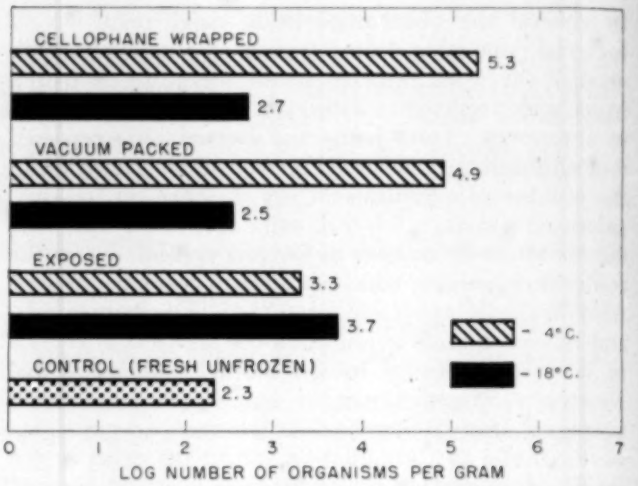

FIG. 3. Number of lipase forming organisms in frozen pork after 12 weeks storage.

perature. There was a slight reduction in the number of *E. coli* surviving in the exposed samples at 0° F. (—18° C.) and about a ten-fold reduction in the most probable number recovered after storage in the protected samples at 25° F. (—4° C.). At this temperature the vacuum-packed samples had somewhat higher counts than the cellophane-wrapped. All but one of the unprotected samples stored at 25° F. (—4° C.) were negative for *E. coli*.

Yeasts and molds do not constitute nearly so great a problem in the preservation of meats as they do in the preservation of fruits and vegetables. However, certain deteriorative changes, such as black spot, are associated with mold growth on meats stored at temperatures near 32° F. (0° C.) and it was thought advisable to consider these organisms in the course of the frozen pork study. Plates were poured with wort agar from the same dilutions used for bacterial counts and the results recorded as total yeast and mold counts. These counts were considerably higher than the control counts for meats stored at 25° F. (—4° C.) and considerably lower than the control counts for samples stored at 0° F. (—18° C.), but there was excessive variation between individual samples.

Although quantitative information on bacteria in frozen meat is interesting and such results as have been presented here suggest other lines of research that might be followed in the future, the bacteriologist working in this field is also concerned with the particular kinds of organisms that might be encountered.

The psychrophilic organisms that are capable of growing in frozen meat at or below 32° F. (0° C.) are particularly interesting to us. Since there are not many descriptions of these organisms in the literature, a resume of some of our isolates may be of value to other workers.

One group of such organisms was isolated from a slimy growth on frozen lamb legs that had been wrapped in cellophane and stored at 25° F. (—4° C.) to accelerate the chemical changes which were studied. This slime, when treated as outlined above, yielded cultures of eight gram negative, non-sporeforming motile bacilli. All eight cultures grew well at 39° F. (+4° C.) on

agar slants, showing macroscopic growth in 36 to 48 hours and luxuriant growth in 72 hours. Growth on slants incubated at 21° F. (—6° C.) was fairly heavy in 1 week. No growth was obtainable on agar slants incubated at 18° F. (—8° C.), but in Difco veal infusion medium slight colony-like growth was discernible in 3 to 4 weeks. None of these organisms could grow at 99° F. (37° C.) and the optimum growth temperature for all was about 68° F. (20° C.).

Culture Nos. 1 and 2 proved to be members of the family *Enterobacteriaceae*. Growth on agar slants was translucent and slightly bluish for the first 48 hours and older cultures developed considerable soluble brown pigment. The cultural characteristics of these organisms are shown in Table 1. Although they are evidently members of the *Enterobacteriaceae*, they do not readily fit into any of the existing classification schemes and their inability to grow at 99° F. (37° C.) is certainly anomolous. They are similar to *Aerobacter cloacae* of Bergey as reported by Breed and coworkers *(2)* but could hardly be included in the *Aerobacter* as now understood because of their peculiar I M Vi C formula. If one turns to some of the newer proposed classifications he could class the organisms as *Colobactrum aerogenes* according to the scheme of Borman, Stuart, and Wheeler *(1)* or place them in the irregular group of Griffin and Stuart *(6)* and Stuart, Griffin, and Baker *(13)*. The latter authors, using the familiar I M Vi C reactions plus gas production in cellobiose, have recognized a group having the formula −+++ which is transitory between an intermediate group and the genus *Aerobacter*. Our organisms apparently belong to such a group.

The occurrence of psychrophilic bacteria is frequently explained by saying that the psychrophils are organisms that have been adapted to growth at lower temperatures through more or less unusual circumstances. It is interesting to note, in this connection, that our cultures 1 and 2, which show all the characteristics of coliform organisms except temperature requirements, have not gained the ability to grow at 99° F. (37° C.), even after 2 years' cultivation in the laboratory. Transfers from cultures that had been maintained at room temperature did not seem to be different, in their temperature reactions, from subcultures of strains maintained in the refrigerator.

Table 2 shows the principal cultural characteristics of other groups of psychrophilic organisms isolated from frozen meat. The first six cultures were isolated from frozen lamb and are the remainder of the eight cultures mentioned above. They are members of the genus *Pseudomonas* but not classifiable as to species using the key in Bergey's manual *(2)* All produced a yellowish green pigment and had the same temperature reactions as the two coliform organisms described above. They produced an alkaline reduction of milk, did not reduce nitrates to nitrites, and in addition to the fermentation reactions shown in the table fermented galactose with the formation of acid but attacked no additional carbohydrates.

The next group of ten cultures shown in Table 2 were isolated from frozen pork in the course of the study described above by isolating characteristic colonies observed on the plates poured for counting. All these cultures grew rapidly at 36° F. (+2° C.) and showed macroscopic growth on agar slants in 1 week at 25° F. (—4° C.). They are likewise members of the genus *Pseudomonas* but produced tan to brown rather than greenish pigment, did not reduce nitrates to nitrites, caused an alkaline reduction of milk, and also fermented galactose but no sugars in addition to those shown. They are somewhat similar to *Pseudomanas geniculata* (Wright) Chester *(2)* but the description of that organism is not sufficiently complete for a certain identification.

The next group of 14 isolates was the same in all particulars as the previous group of ten, except that these isolates were characterized by slow urease production. They did not utilize urea within the 48 hour period specified for the genus *Proteus* but did show positive reactions in the Rustigan and Stuart urease test medium in 4 to 5 days incubation at 20° C. In type of motility and colony form they resemble the *Pseudomonas* genus more than they do *Proteus*.

The group of four gelatin-liquefying, non-motile rods seems also to belong to the *Pseudomonas* group but again does not fit any of the recognized species. The biochemical and temperature relationships were the same as those of the two previous groups of psychrophils isolated from frozen pork.

Finally we have a group of very short, oval, non-motile, non-proteolytic, and non-fermentative rods also

TABLE 1

Reactions of Cultures 1 and 2 [1, 2]

Culture No.	Catalase	Urease	H_2S	NO_3 red.	Dextrose	Lactose	Glycerol	Cellobiose	Gelatin liq.	Milk
1	+	−	−	+	AG	AG	A	AG	+	Acid red.
2	+	−	−	+	AG	AG	A	AG	+	Acid red.

[1] I M Vi C = −+++. [2] Acid and gas also produced in: Maltose, Xylose, Arabinose, Salicin, Galactose, Raffinose and Manitol.

TABLE 2

Cultural Characteristics of Psychrophilic Bacteria [1]

Number of isolates	Source	Gelatin liquefied	Motile	Dextrose	Arabinose	Xylose	Urease
6	Frozen lamb	+	+	A	N. C.	N. C.	−
10	Frozen pork	+	+	A	A	A	−
14	Frozen pork	+	+	A	A	A	Sl. +
4	Frozen pork	+	−	A	A	A	−
4	Frozen pork	−	−	N. C.	N. C.	N. C	−

[1] All were gram, H_2S, Indol, and Voges-Proskauer negative rods.

isolated from frozen pork. This was the only group of organisms shown in Table 2 which reduced nitrates to nitrites. In view of the slight biochemical activity this group is probably of only minor significance. These organisms are probably members of the genus *Achromobacter* but do not fit exactly any of the species described.

Summary and Conclusions

Studies on frozen pork packaged in various ways and stored at 0° F. (—18° C.) and 25° F. (—4° C.) for 12 weeks showed that:

1) Aerobic counts made at 99° F. (37° C.) decreased during the storage period for all samples, regardless of storage temperature and protective methods.
2) Counts of total aerobic and lipase-forming organisms made at 68° F. (20° C.) increased during the storage period. This increase was particularly great for protected samples stored at 25° F. (—4° C.), but was also evident for samples stored at 0° F. (—18° C.).
3) The most probable number of coliform organisms was reduced greatly during storage at 25° F. (—4° C). in protected samples but was only slightly reduced in similar samples stored at 0° F. (—18° C). In unprotected samples the coliform counts were slightly reduced during storage at 0° F. (—18° C.) and approached extinction in unprotected samples stored at 25° F. (—4° C.).

Two cultures of psychrophilic paracolon organisms and six *Pseudomonas* strains were isolated from frozen lamb. Twenty-eight *Pseudomonas* and four *Achromobacter* strains were isolated from frozen pork. All grew rapidly in the range of 25° F. (—4° C.) to 21° F. (—6° C.). The cultural characteristics and classification of these organisms have been discussed.

The evidence presented for the ability of many bacteria to multiply in meat during freezer storage, particularly at high freezer temperatures, together with the ability of coliform organisms to survive well in adequately protected meat samples stored at 0° F. (—18° C.), emphasizes the necessity for handling meat intended for freezer storage in a scrupulously sanitary manner. Only by asuring a low bacterial load on the fresh meat at the time of freezing can one be sure of low counts on the product when removed from the freezer.

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Measurement of Sensory Differences[a]

DAVID R. PERYAM and VeNONA W. SWARTZ

Quartermaster Food and Container Institute for the Armed Forces, Chicago, Illinois

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There is great need for objectivity in the field of flavor measurement. Relatively greater objectivity is possible by use of tests which depend upon discrimination rather than upon judgment. Three such tests designed for the measurement of sensory differences are described, and a method for statistical analysis of the results is suggested.

Quality, as determined by the ultimate crucial test of consumer acceptance, is paramount to every food processor, and, concomitantly, to all those who are engaged in food research and development. Consumer acceptance of a food product is conditioned largely upon its flavor quality, i.e., all those properties affecting human senses of taste and odor which determine its pleasantness or unpleasantness. Other aspects of a food are important in determining its total worth, such as nutritional adequacy, microbiological purity, and chemical stability; but without satisfactory flavor quality, it may not matter that a food is otherwise good, for a

[a] This paper reports research undertaken by the Quartermaster Food and Container Institute for the Armed Forces, and has been assigned Number 289 in the series of papers approved for publication. The views or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or indorsement of the Department of the Army.

food product which is adequate in every other way may be rejected by individuals and by whole sections of the population simply because "it doesn't taste good."

These secondary aspects, if we may call them that, are relatively easy to deal with. Ordinarily prediction may be made and control effected in these areas by standard scientific techniques if proper equipment and trained personnel are available. But in the crucial aspect of flavor quality, the *sine qua non* of consumer acceptance, we encounter a more difficult situation. Food technologists today are becoming aware of the problem but few face it in a realistic manner. Attempts to deal directly with flavor problems have generally been variable and not characterized by precision. This results from the fact that flavor problems as a whole belong to a field which is diffuse and many-sided, while individual problems may appear deceptively easy and hence become dangerously subject to oversimplification. Add to this the fact that there exists no standardized methodology in this field and it is understandable why many food processors choose to trust solution of their flavor problems to luck, aided perhaps by careful attention to process variables, rather than to subject them to direct attack.

Why is there this tendency toward oversimplification in a complex field, this lack of appreciation of the true difficulties involved? While everyone is aware that a vitamin assay, to take an example, requires both special equipment and a special knowledge on the part of the analyst, when a problem of flavor evaluation arises the researcher may reason like this, "What equipment is required? Why, simply normal human senses such as are available to me and to everyone else. What know-how is required? All one has to know is what he has tasted and how to describe it. Anyone can do that if he only stops to think. So the boys and I will just sit down and taste it ourselves." Such a simple, naive philosophy is not far removed from the flavor control method that is in most common use, i.e., the small panel technique using a score card with an arbitrary scale. Even though it is basically naive, the panel technique can be worthwhile if used properly and in some situations it is the only approach possible. But it is used indiscriminately and in many cases it results in great sacrifice of precision or even in utter failure to obtain useful information. Quality measurement has a world of possibilities not revealed in this simple philosophy.

When predictions fail in the realm of flavor quality there is a tendency to say: "People differ. Their sensory capacities differ. Also, there is no accounting for tastes. You can't expect precision when you are dealing in human behavior." This is but apology. People are also much the same, their sensory capacities are a biological fact, and even their preferences and their judgments are subject to quantitative description. We must recognize stability as well as variability. Science measures in such a way that the measurements can be used for prediction and control. Human behavior can be dealt with scientifically, just as can the subject matter of physiology, physics, or chemistry. However, knowledge of the techniques required is not wide-spread. This is particularly unfortunate for food technology because of the vital problem of flavor which must, by its very nature, be dealt with in terms of human behavior.

The great need in the field of flavor measurement is objectivity,—test methods which will permit the interpretation of results at a level higher than that of pure speculation. Too often many variables are allowed to operate at once, as for example, in the typical score card system where a number of factors, each measured subjectively by judges who we only hope are all doing the same thing, are converged into a single scale value. The result is likely to be a meaningless artifact, accepted in resignation because there is no better. The constant aim should be to reduce as far as possible the number of variables simultaneously operating, in a manner analogous to the way control is effected in the physical sciences. This not only avoids equivocation in interpretation but has the corollary effect of making the problem for the individual observer less complex.

A test should set a critical situation in which units of human response can be counted and handled statistically. We are on firmer ground when we deal thus with discrimination rather than with judgments. Admittedly it is not always possible to avoid the psychologically complex activity implied by the term "judgment," nor would we want to do so, for that activity has many proper uses, such as the rapid estimation of pleasantness value of foods or the measurement of purely subjective factors. But there arise many problems which may be attacked directly by what we may call discrimination tests. One such problem is the determination of the existence of a difference between foods which is capable of detection by sensory means. This problem is particularly easy to solve by objective testing.

This article presents three tests designed for difference testing, all of which fulfill the criteria of objectivity and ease of interpretation. They are variants of one basic type, but each of them has certain advantages. Each sets a definite discrimination problem in such a way that the observer can give a positive straightforward answer, and results in each case can be interpreted statistically.

The general concept of difference testing based upon discrimination rather than judgment is not a new one. Methods suggestive of that principle have been described in the food research literature from time to time but the principle has never been carefully formulated. The methods herein described were worked out in the Quality Research Laboratory of Joseph E. Seagram and Sons in Louisville, Kentucky, in 1941 and 1942, and since then that company has been using them with marked success in both quality research and production control. The use of these methods in certain problems of product analysis has been described *(5)* by the founder of the Seagram Laboratory, Dr. E. H. Scofield, who was the major contributor to their development. One of the three, the triangular test, was developed independently of Seagram's work, in the research laboratory of the Carlsberg Breweries, Copenhagen, Denmark, where it has been used for control work and for selection of taste panels. The form of the test used there is the same but the test conditions do not appear

to be as well controlled. The work was published in the United States in 1946 *(3)* and the method is sometimes referred to as the "Helm technique." In 1936 *(1)* and again in 1940 *(2)* Cover published articles describing a test procedure which she named the "paired eating method" and which she employed to measure differences in regard to tenderness and other qualities in meats. It is an objective method which requires meticulous control of most test variables and which produces data capable of statistical verification. It is quite similar to the duo-trio test of the present paper except that it does not use a reference standard.

The Food Acceptance Laboratory of the Quartermaster Food and Container Institute has recently adapted these efficient sensory research tools, in the forms herein described, to a wide variety of food research problems where their utility has been further demonstrated.

The Duo-Trio Test

Of two products which are to be tested for difference one is selected as the "control." Logically, either of the two may be used, but if either is more familiar to the subjects or if either is more likely to be considered as normal, that one should be selected. For example, when checking a stored product against the fresh product for possible deterioration, always use the latter as control. Uniform samples of the control and of the unknown being tested are prepared and are presented to the observer in succession. The observers should be thoroughly familiar with the test and should know the entire sequence of samples, except, of course, the order of the critical pair. These are the basic instructions for the test:

"First you will be given a warm-up sample. This will be the same as the control sample which follows but be prepared to disregard it, for it is apt to taste different merely because it is first. It is given to you only to get the flavor in your mouth. Rinse your mouth with the water which is provided after this sample and also after each of the samples which follow. Next you will get a control, and following that, two samples in unknown order. One of them will be the same as the control but the other will be different. It is your problem to say which one of the two, whether the first or the second, is the different one."

The observer is required to give a decision, being instructed to make a "best guess" if he is not sure. The reason for forcing a judgment will be apparent when we consider the method of summarizing results. We have found that with most food substances tested two of these basic test units can be presented at a single sitting without apparent effect on the precision of the results. The rinse water should be of the most neutral character obtainable. The distilled water which is available in some laboratories may not be as good for this purpose as tap water, but, in any event, the emphasis should be on low intensity of flavor. The rinse water should be the same temperature as the test samples when tests are run at room temperature. When testing heated samples, the rinse water should be at, or slightly above, normal body temperature. The routine of a single sitting for a subject is diagrammed in Figure 1.

It is essential that certain variables be rigidly controlled in order to assure that accidental differences do not affect the results and that maximum precision is attained. The samples as presented to the observer

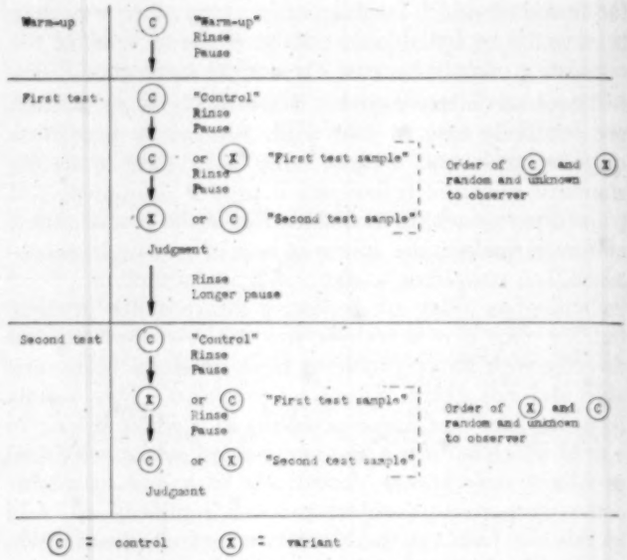

FIG. 1. Diagram of procedure of duo-trio taste test.

must be exactly alike in respect to all factors under experimental control. They must all be at the same temperature, must be presented in identical containers, and must be of the same size. To insure effectiveness of quantity control the amount must be no larger than can comfortably be taken into the mouth at one time and observers should be instructed to handle them in this manner. The products must present the same visual appearance. Although differences in appearance can also be tested by this method, it must be done in a separate test. Determination of the order of the samples within the unknown pairs should be made by some method which insures randomness. If this is not done, the observers may try to "outguess" the experimenter, either consciously or unconsciously, and when this happens, the results bear little relation to the object of the test.

To insure efficiency on the part of the individual observer, the factors of adaptation and mutual interference between samples must be controlled. The "warm-up" and the rinse between samples are both for this purpose. Also, a standard framework of test procedure must be maintained. The time interval between samples is a critical point. Two factors, adaptation and forgetting, work in opposition. On the one hand the time interval should be extended as far as possible to permit sensory recovery, but, on the other hand, it must not be too long because forgetting becomes increasingly important as the interval is extended. The best evidence indicates that the interval should not be less than 10 seconds nor greater than 30 seconds. It may be varied according to the degree of adaptation induced by the substances tested and according to the skill of the observers.

The practice of having each observer make two judgments is a matter of convenience only. For example, the test would be meaningful whether 20 observers gave one response each or one observer repeated 20 times. However, it should be kept in mind that the method measures differences only as perceived and responded to by the observers actually participating. Both skill in the testing situation and sensitivity will vary a great deal, not only from one person to another, but to a lesser ex-

tent from time to time with a single person. It is less significant to establish that one or two exceptional individuals can reliably distinguish between two products than it is to show that a larger group will detect the difference. In using a limited number of observers oversensitivity is seldom a problem. The great danger is that the observers may be operating below the optimum and thus fail to detect a substantial difference. The best solution is to have a group selected on the basis of their sensitivity and their skill on this specific procedure and to use a large enough number on any one test to level out chance fluctuations in individual performance. Then one can be reasonably certain that difference ratings are not only comparable but also meaningful.

Tabulation of the test data will give a certain number of correct identifications which can be stated as a percentage of the total judgments. From the test situation itself, which requires guessing in case of doubt, it can readily be seen that when there is no difference between samples chance alone should result in about 50 percent correct identifications. (Here "correct" means merely that the observer chooses the test sample rather than the control.) It can be shown theoretically, and verified experimentally, that the testing of identical samples will result most often in 50 percent "correct" responses, a situation analogous to getting 10 heads and 10 tails in 20 tosses of a coin, and in higher or lower percentages with continually decreasing frequencies. The probability of obtaining any given percentage correct in this situation can be determined by any one of several methods. When a difference exists between the products tested, however, some of the observers will detect it and their responses will no longer be guesses but will tend to be right more often than chance alone would allow. As the degree of difference becomes larger, more observers will detect it or will detect it more often and the percentage of correct judgments will increase correspondingly. To determine the significance of any given result the problem becomes that of determining how often one would expect to obtain that percentage correct had the samples been identical. The smaller this expectancy, the higher the level of confidence one can have in the result, i.e., the greater the certainty that a true difference exists between the products. One fairly simple method of calculating this expectancy is presented here.

A statistic known as the Critical Ratio is derived. This is the ratio of the difference between the two percentages (the percent correct actually obtained and the theoretical 50 percent "pure-chance" result) to the Standard Error of the latter percentage. The applicable formulae are:

$$\text{C.R.} = \frac{p_{obs} - p}{\sigma_p} \qquad (1)$$

$$\sigma_p = \sqrt{\frac{p\,(1-p)}{N}} \qquad (2)$$

where C.R. = Critical Ratio; p_{obs} = observed percentage (or proportion) correct; p = percentage (or proportion) correct expected by chance; σ_p = standard error of p; and N = total judgments.

By solving equation (2) for p = 0.50 and substituting in equation (1), the latter can be reduced to simple form, as follows:

$$\text{C.R.} = \frac{p_{obs} - 0.50}{\sqrt{\frac{0.50 \times 0.50}{N}}} = \frac{(p_{obs} - 0.50)\sqrt{N}}{0.50} \qquad (3)$$

Figure 2 shows a typical data sheet with the Critical Ratio calculated using formula (3). The significance of the result is determined by using the tables of areas under the normal curve with the C.R. figure as a positive sigma distance. The tables will give the proportion of the area lying below this point and by subtracting this from 0.50 one gets the proportion lying beyond. This is also the expectancy, in terms of chances in 100, that identical samples would have given the same result; hence, the smaller this figure becomes, the greater is the confidence one can have that a true difference is represented. This is the concept usually referred to as "confidence level" or "level of significance." The data of Figure 2 give a confidence level just slightly poorer than 1 percent, which is considered very significant.

Date: December 22, 1949

DUO-TRIO DIFFERENCE TEST

Sample No. 1 -------- (Control)
Sample No. 2 -------- (Variant)

Observer	Order of Unknowns 1st	Order of Unknowns 2nd	Judgment 1st	Judgment 2nd
DG	1-2	1-2	X	X
CB	1-2	2-1	X	0
SB	2-1	1-2	X	X
DP	2-1	2-1	0	0
CH	2-1	1-2	X	X
MB	1-2	2-1	0	X
ML	1-2	1-2	X	X
RS	2-1	2-1	X	0
AE	1-2	2-1	X	X
MT	2-1	1-2	X	X

X = Correct judgment
0 = Incorrect judgment

Total judgments = 20
Number correct = 16
Percent correct = 75%

C.R. = $\frac{.75-.50\ \sqrt{20}}{.50}$ = 2.23

Significant at 1.3% level of confidence

FIG. 2. Typical data sheet for the duo-trio test, showing statistical summary.

There are several methods available for analysis of these data. Helm and Trolle *(3)* used the chi square method which, with 20 or more judgments, will give results identical with those obtained by the Critical Ratio method described here. Also, exact probabilities can be calculated by the binomial expansion theorem. This latter method involves considerable labor and is probably not worth while when dealing with larger numbers of judgments since approximations obtained by the other methods are very close when N is 20 or more. However as N is reduced the error arising in both the chi square and the Critical Ratio methods becomes progressively larger and neither should be used when N is less than 16. Below this point the exact probabilities should be calculated by the binomial theorem.

The Triangular Test

This test presents to the observer a problem which, psychologically, is somewhat more complex than that of the duo-trio test, and in which controlled conditions are not as easily maintained; however, it has been found to give greater precision in many instances. It need not be considered as merely a short-cut, although it does have the added advantage of being easier to conduct and requiring less of the experimenter's time. Also, when a readily detectable difference exists, fewer

judgments are required to attain statistically significant results.

A control is used, although it need not be so designated, and the same recommendation that the more familiar of the two samples be used as control applies here also. The critical samples are a trio of unknowns, two controls and a variant, presented simultaneously. The instruction to the observer when this method is used in a taste test is as follows:

"You will be given a warm-up, after which you will rinse. Then you will be given three samples at the same time. Two of these are identical and one is different. You are to pick out the different one. You should proceed slowly, take as nearly as possible the same amount of sample in each taste, and rinse and pause after each taste, in order to avoid interference between samples."

If the substance under test is not so intense in flavor that recovery from adaptation will be slow, a second "triangle" may be given after a relatively short rest, so that we can diagram the procedure of one sitting as shown in Figure 3.

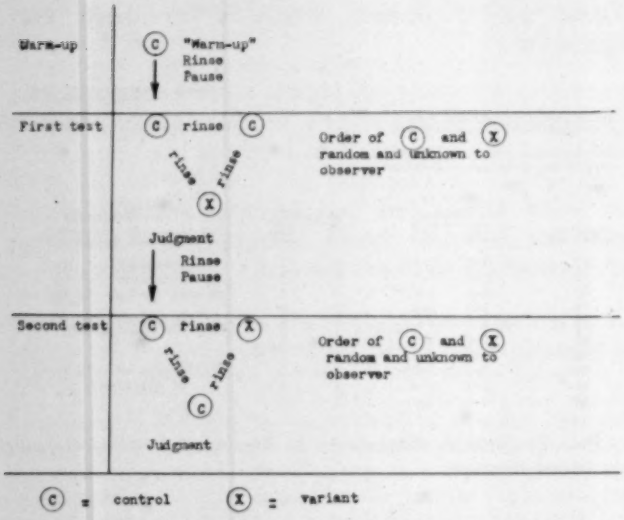

FIG. 3. Diagram of procedure in the triangular taste test.

Here control of amount tasted, and control of adaptation by use of proper time intervals and rinses, must be the responsibility of the individual observer. For this reason a more thorough training is required if the test is to have maximum precision. The total quantity of sample provided should be such that the observer can check back two or three times if he wishes.

Statistically the data are analyzed just as with the duo-trio test, the only change being that here the expected percentage of correct judgments, if all samples were identical, would be 33-1/3 percent since the observer has only one chance in three of guessing the correct sample. Solving equation (2) and equation (1), as before, using $p = 0.33$:

$$\text{C.R.} = \frac{p_{obs} - 0.33}{\sqrt{\frac{0.67 \times 0.33}{N}}} = \frac{(p_{obs} - 0.33)\sqrt{N}}{0.47} \qquad (4)$$

For example, if 12 correct judgments are obtained in a total of 16 responses, we have:

$$\text{C.R.} = \frac{(0.75 - 0.33) \times \sqrt{16}}{0.47} = 3.6$$

A slightly different method of analysis of triangular test data, but one which yields identical probability values, is described by Roessler, Warren, and Guyman *(4)*.

The Dual-Standard Test

This test is substantially the duo-trio test adapted for use with odor samples. Taking advantage of the fact that recovery from odor stimulation is much more rapid than is recovery from taste stimulation, the observer is provided with a pair of standards, the control and the variant, rather than just the control presented singly, for study prior to presentation of the unknown pair. This gives him an opportunity to develop a more definite criterion of difference, and precision is bettered as a consequence. This basic instruction is given to the subject:

"Here are two odor samples. Note that one is marked "S1" and the other is marked "S2." You are to study these. Note any differences, smelling back and forth until you believe you can tell them apart. Then you will be given this second pair of samples. They are the same as the first but are unidentified. It will be your problem to decide which one of them is like S1 and which is like S2. Do not hurry. Smell the samples of the pair alternately and pause four or five seconds between sniffs. It is suggested that you smell each sample no more than three times. You may check back on the standards if you wish."

The procedure is shown in diagram form in Figure 4.

This test should be conducted in a room where the air is free from definite extraneous odors. The samples should be held in closed containers: 200-ml. Erlenmeyer flasks with ground-jointed stoppers are very convenient for this purpose. The flasks should be opened only while actually being smelled. The untrained observer will have a tendency to alternate too rapidly between the samples on this test so the part of the instructions relating to the time interval must be particularly emphasized during training. If strong odors are being tested even more time should be allowed between sniffs. When dealing with rel-

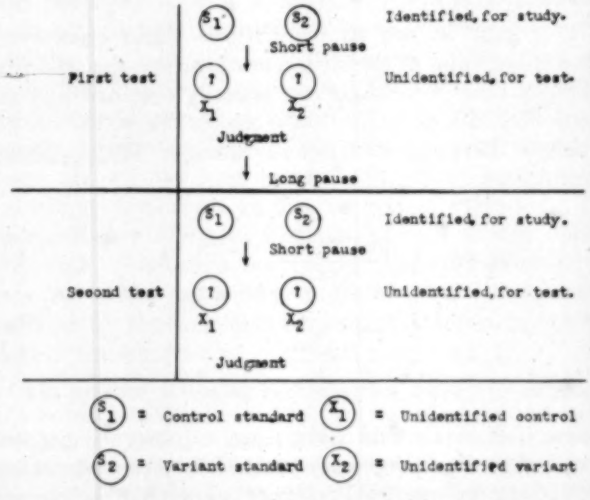

FIG. 4. Diagram of procedure in the dual-standard odor test.

atively weak odors such as are normally encountered with food products, an observer can give even more than two responses at a single sitting if a recovery period of about one minute is given after each judgment.

Analysis of results on this test is done exactly as for the duo-trio test.

Discussion

Theoretically, any one of these forms could be used for any type of testing: taste, odor, or appearance. Actually, in many instances one form will serve equally as well as another so that the experimenter may choose the one which is most convenient or which can be handled with greatest ease by the observers available. However, there are certain limitations and advantages of each of the three forms which should be kept in mind.

1. *The Duo-Trio Test.* This form has an advantage for taste tests in that it permits more definite control of the observer as, for example, in the matter of time interval and quantity of sample. Its superiority is limited to taste testing since successive presentation of samples is unnecessary and even confusing in odor and appearance tests. It requires careful attention on the part of the laboratory operator. When a difference is fairly evident so that guessing is infrequent, more judgments are required to establish that difference at a given level of confidence than with the triangular test. But with trained operators and a smoothly working laboratory it can give maximum precision.

One example of consistently good results with this method in the Food Acceptance Laboratory has been in the investigation of dried whole milk—tested in its reconstituted form. It has been used first to select a panel of observers of superior sensitivity and then to measure, in terms of this panel's skill, differences caused by deterioration and by processing variables. The flavor of milk seems to be well suited to discrimination in this highly controlled testing situation.

2. *The Triangular Test.* As pointed out before, when this form is used for taste, it is more difficult to maintain experimental control than in the duo-trio, since the responsibility for timing, rinsing, and quantity taken at one time lies with the observer. However, training can overcome this disadvantage and the method in many instances gives more precise results than the duo-trio. Even though the situation, with three unknowns simultaneously under consideration, is psychologically more complex, it definitely helps the subject to remember the samples when he can place them in a visual-spatial frame of reference and also can check back on previous impressions. This factor seems particularly advantageous in testing complex flavors while the more controlled duo-trio is superior when simpler flavors are compared. This form can be used for odor tests, where it is faster than the dual-standard form but it does not give as precise results. It is probably the best of the three for tests involving differences in appearance.

The triangular test has been used in the Food Acceptance Laboratory for a wide variety of difference problems. A good example is that of the evaluation of imitation peppers in terms of how closely they approximate natural peppers in strength and quality. Weak water infusions of both peppers are made up by a standard procedure and are presented in the triangular test to trained observers using the natural spice as the control. Tomato juice seasoned at normal levels is also used as a testing medium. The triangular test has been shown to give better discrimination between peppers than the duo-trio when using either the water infusions or tomato juice.

3. *The Dual-Standard Test.* This is the best form for odor testing because the second standard permits the observer to form a more stable criterion of what to look for in the unknowns. In taste testing, however, presentation of the second standard is a disadvantage since both forgetting and adaptation are enhanced by the lengthened series. An illustration of a problem in which the dual-standard odor test was particularly applicable was the possible effect of various fumigants on stored spices. Standard water infusions were made of the spices that had been in the fumigated area and of controls which were untreated but otherwise matched with the fumigated samples. The control and treated sample were then tested for odor difference by the dual-standard method.

All three forms test only for differences, as such, and are not designed to give information about preference or superiority. This should not be considered a limitation for it arises from the fact that we have purposefully isolated a single factor for experimentation. We can be certain that results are more valid for this very reason. Once the basic fact of difference has been established, one can test further by other means to determine the corollary effects of that difference.

A word of caution about the results of the statistical analysis is in order. The Critical Ratio figures will look like difference scores. If Product A differs from the control by 2.0 C.R.'s and Product B from the same control by 2.7 C.R.'s, there will be a strong tendency to assert that Product B differs by a greater amount. Actually this may be so, but, statistically, we have no information on the matter; we can only say that we have established the "B"-difference to a higher degree of certainty. The validity of using these C.R. figures as actual difference scores is being tested in the Food Acceptance Research Laboratory at the present time.

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Breakfast Cereal Technology[a]

S. F. BROCKINGTON

Research Laboratories, The Quaker Oats Company, Chicago, Ill.

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(REVIEW PAPER)

An outline is presented of production practices and problems encountered in the manufacture of several types of breakfast cereals.

In breakfast cereal production, there seems to be more of simple trial and error and less of the scientific approach. This is not surprising because of the extreme complexity of cereals. The raw materials, the cereal grains, are complex systems of proteins, carbohydrates, fats, enzymes, minerals, and vitamins, each of which has been the object of much study and research. The literature on proteins alone fills volumes. Add to that all the published material on starches, sugars, fats, and vitamins, and it is no wonder that in cereal production we have been content to try this and that rather than to proceed on what could have been learned from the literature. Things are changing, however, and cereal producers now have well equipped laboratories for research and quality control.

In some of its aspects, cereal technology is analogous to chemical engineering in that unit processes such as cooking, flaking, rolling, puffing, and drying are involved.

Hot Cereals

Hot cereals, or those that require cooking, consist of two types: granular products such as farina, whole wheat, and corn meal; and flaked products such as rolled oats and rolled wheat.

Farina is produced in the flour milling process and is principally wheat endosperm. Granular whole wheat contains all of the bran, germ, and endosperm. It is produced by grinding cleaned, washed wheat in granulating rolls and is sifted on bolting reels. It is necessary in making this product to maintain uniform granulation. It must contain a minimum of coarse bran particles which make the texture of the cooked porridge objectionable and be free from floury material which causes lumping and mushiness when cooked.

The principal steps in rolled oats production are cleaning of the raw grain, drying, hulling, removing the hulls, and steaming preparatory to rolling. Drying of oats can be done on rotary or kiln type driers. Rotary drying is fast and economical, whereas kiln drying is slow. Drying kilns consist of steam-jacketed stacked pans. In this type of drying the oats are heated for a much longer period of time than in rotary drying. Drying is necessary to facilitate hulling, and the simultaneous heat treatment is also necessary for flavor development. We do not know whether rotary or kiln drying is the better method, but have found that enzymatic activity in finished rolled oats is different when made from rotary dried as compared with kiln dried oats.

The control of enzymatic activity is a function of the relative humidity of the drying air. Enzymatic activity may be a factor in flavor development. Control of enzymatic activity is involved in shelf life and preservation of original fresh flavor. This is an interesting field of investigation for the cereal technologist, and much research is needed on the flavor development of rolled oats.

Hulling is done on impact machines in which a high-speed rotor receives the oats, and they are impacted lengthwise against a rubber lined stator. The hull is split off, and the oat kernels or groats are released. Hulling used to be done on milling stones, and it was necessary to reduce the moisture to about 6 to 8 percent.

The milling process after hulling involves complete separation of hulls from groats and elimination of weed seeds, sticks, and stems left over from the grain cleaning process. This is no small task, much machinery is involved, and constant control is necessary. Frequent checks are made by hand picking of samples taken from the machines to make sure that all foreign material is eliminated. Hulls are particularly objectionable to consumers when found in the cooked cereal.

The next critical operation is rolling. Just enough steam and water are added to temper the groats so that they will be pressed into flakes without shattering and with minimum formation of fine material. Constant attention is required at the rolls, and control measures are necessary to insure uniformity of flake size and thickness. Two types of flakes are produced, i.e., those rolled from whole groats (so-called "old fashioned" rolled oats) and those from groats cut on rotary cutters (so-called "quick" rolled oats). The cooking time required for the latter is less and is related to the size and thickness of the flakes. While it is possible to produce a very thin flake that would be cooked almost instantly in boiling water, it is not practical to package such a product, because of breakage. We should like to know how to make rolled oats that would be "instant" cooking, but at the same time would not break up. This is another interesting research problem for the cereal technologist.

It is necessary to control the moisture content of the product leaving the rolls. If packaged at or above 12 percent moisture rolled oats become moldy. It has been found that mold will develop on various food materials when the surrounding air is above 75 percent relative humidity.

It is frequently asked if there is any difference between the regular or old-fashioned and quick rolled oats. The only difference is in particle size. It should be emphasized that rolled oats are a whole grain cereal

[a] Presented before the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 22, 1950.

which contains bran, germ and endosperm. Nothing but the hull or chaff is taken away, and nothing is added.

Rolled wheat is produced in much the same way as rolled oats. Whole grain wheat is steamed and rolled, and the chaff is readily removed from the kernel. In fact, its removal occurs largely at the time of thrashing on the farm and is therefore not a processing problem.

Ready-to-Eat Cereals

These require no cooking and are served directly from the package. The most interesting of this group are the puffed cereals. Puffed rice was introduced in 1904, and puffed wheat in 1907. There is a dramatic history behind puffed cereals. At the turn of the century Dr. Alexander P. Anderson, who was studying the structure of starch granules, placed small test tubes containing cornstarch and wheat flour in an oven at 500° F. for 5-10 minutes until the contents began to change from white to yellowish brown. The tubes then were removed and quickly broken. Anderson observed that the starch granules had been exploded and that the structure had been changed to a porous puffed mass. He had thought that exploding starch in this manner would result in a product similar to cooked starch. Instead, he obtained this new kind of material. He was satisfied that free water in the starch nucleus, unable to escape during heating because of the pressure, had flashed into steam at the moment of the explosion and changed the structure of the starch granules. From these experiments came puffed wheat and puffed rice.

The manufacturing process is still basically the same as that of Anderson's experiment. The grain is heated in a closed chamber known as a "gun" in which pressure is built up by steam and then suddenly released. This process can be carried out in a number of different ways. The gun can be stationary or rotating and can be either heated externally or be unheated. Ten to twenty pounds of clean grain are dropped into the gun, which then is tightly closed, and the grain is heated. Steam pressures up to 275 p.s.i. are applied. After a short cooking time the gun is suddenly opened and the puffed grain is caught in metal hoppers. The product is screened, dried, and cooled. For enrichment, vitamins or minerals can be added just before packaging by a process to be described later.

The various steps in the puffing cycle are quite critical with regard to time of treatment, grain temperatures, and steam pressure. The processing conditions vary with the type of grain; e.g., hard and soft wheats require different treatments. Moisture in the original grain and that involved in the process of steaming within the gun play important roles not yet fully understood. If the surfaces of the kernels become too wet during the process, poor expansion results and loss of sheen becomes evident, particularly in puffed rice.

Exactly what happens to grain in the puffing process is not known. Starch is radically changed. Anderson's theory of the role of free water in the explosion of starch granules does not explain all the facts. In our laboratory we have studied changes in starch viscosity with the amylograph, a recording viscosimeter. Puffed grains exhibit amylograms quite different from those of raw grains.

Another type of ready-to-eat cereal comprises the flake cereals, which are made from cooked grains. Rice flakes, wheat flakes, and corn flakes are examples. Wheat, polished rice, or corn grits are cooked with sugar, malt, and salt until soft, then partially dried. Some processors allow a tempering or resting period before flaking on rolls. Cooking time varies from 1½ to 3 hours under pressure.

Cooking wheat involves the problem of flavor penetration. If the bran coat is intact it is difficult, if not impossible, for the sugar, malt, and salt to penetrate the grain. It is necessary first to scarify the bran coat by abrasion ("pearling") or fracturing the grain by passing it through rolls under light pressure, enough to rupture the bran without breaking the kernels. Polished rice, being free of bran, does not present this problem. Pearling is not feasible with soft wheat because the products lump up readily. The main aim of the process is to produce tender, flavorful flakes.

Enrichment is added after rolling and consists of such vitamins as thiamine and niacin and of minerals, such as iron, for instance. Then the flakes are toasted in rotary ovens. Flake tenderness depends on thickness and what cereal technologists call "blistering." Blisters are tiny bubbles produced on the surface of the flakes during toasting. They make for more tender flakes that will not lose body when milk or cream is added. Without blisters the flakes are hard and glassy, and they are harsh to eat. Rice and corn flakes blister; wheat flakes do not. We do not know what causes blistering, but it is a combined result of cooking, toasting and moisture. Some technologists think a slight speed differential at the rolls is beneficial. The moisture of the cooked material going to the rolls is certainly important, and humidity control within the toasting oven is also advisable. Such control can be maintained by regulating the flow of air through the oven.

Cooked Dough Cereals

By using cooked doughs, a wider variety of cereals can be obtained than with cooked grains. Such processes also offer greater flexibility in production. A dough can be formed into loaves and then thoroughly baked. When the baked loaves are granulated, ready-to-eat cereals of the Grape-Nuts type are produced. Doughs can be cooked while being mixed. There are a great many ways in which the cooked dough can be handled. It can be extruded into a variety of shapes and styles. Extruded pellets from cooked doughs can be formed into flakes, ranging in tenderness after toasting from no blistering at all to completely expanded, bubble-like flakes.

There are upwards of thirty different kinds of breakfast cereals. This is a fertile field for the ingenious inventor. A survey of the patent literature will show that a lot of possibilities have been proposed, but many of them are impractical for one reason or another.

One may wonder why there are so many breakfast cereals. They are popular because of their convenience, since most breakfasts are hurried, and it is mandatory to reduce cooking and preparation to minimum. A variety is apparently necessary because cereals, as a

class of foods, have a high satiety value. More fundamental research is needed to find why this is so.

Enrichment of Breakfast Cereals

As in all food industries, the cereal manufacturer's first concern is palatability. Consumers are gourmets in varying degrees, but the act of eating food must be a pleasant experience. Incidentally, compatability of aromas and flavors is essential.

It is also true that the food manufacturer has a responsibility to the consumer in that the product he sells should be at least as nutritious as the starting raw materials he uses. The consuming public is becoming increasingly nutrition conscious. The cereal processor has been subjected to a lot of criticism because, it is said, he has been guilty of robbing the public of good nutrition by too much refinement of raw materials. Whether this criticism is justified or not (and there are arguments on both sides), maintaining proper nutrient levels in cereals is a major concern of the cereal technologist. It is being recognized more and more that breakfast is important in the daily diet and that cereals contribute considerably to a good breakfast.

In general, whole grain cooked cereals are not enriched. Farina, a refined product, is sometimes enriched with vitamin D, calcium, thiamine, riboflavin, niacin, and iron. Cereals are low in calcium and relatively high in phosphorous, therefore, the addition of calcium is nutritionally advantageous to produce a proper ratio of calcium and phosphorous.

Puffed goods can be sprayed before packaging with a liquid containing thiamine, niacin and iron. The spray must be in the form of a fine mist, and pneumatic nozzles are used. Coarse sprays cause pitting of the surface of puffed rice and this is objectionable to consumers. It appears to them as though the product has been attacked by insects. Flow meters are used for accurately controlling the flow of liquid to the nozzles. In addition, the flow of puffed goods under the nozzles must be also accurately controlled. Frequent checking of flow rates of product and liquid is necessary. This is a job for the instrument engineer, and photo-electric cells are successfully used for such purposes.

Various types of chemical feeders are used for adding dry enrichment concentrates to flake goods. As the methods of enrichment developed, it has been found expedient to obtain concentrates from commercial firms, who have made intensive studies to find the best way to add them. Corn meal granules and hominy grits, for example, are coated with thiamine, niacin and iron compounds, which are then added to the packaged products in proportions to give the desired enrichment levels. In preparation for cooking, many housewives rinse hominy grits in water. To avoid rinsing loss of vitamins, the grits are treated with thiamine, niacin, and iron in a mixture containing a water repellent material. To make sure that the federal and state laws governing enrichment are complied with, it is customary to add an excess to compensate for unavoidable variation. Thiamine is the least stable of the vitamins used in cereal enrichment, and some losses occur as the product ages. Thiamine nitrate is probably slightly more stable than the hydrochloride in general use.

Protein in Cereals

In the United States, cereals furnish from 28 to 37 percent of the total protein of human consumption. Breakfast cereals contribute a considerable quantity of protein to the diet. While quantity is important, protein quality is of equal significance. The nutritional quality of protein is a function of the amino acids it contains. Of the twenty or more amino acids occurring in foods, ten of these constitute a specific group known as the "essential" amino acids. Thus, milk, meat, and egg proteins are nutritionally superior to cereal proteins because they contain the essential amino acids in a better balance. Rats will not grow on corn as the sole source of protein, but when lysine and tryptophane are added, normal growth results. Many techniques have been evolved for measuring the nutritional quality of protein. In our laboratory, rats are fed rations in which the protein quantity is held at certain levels, and the quality of the protein is evaluated by determining "nitrogen efficiency," that is, ratio of change in weight to weight of protein nitrogen ingested. Direct determination of amino acids by microbiological methods is also used. We have studied the problem of maintaining protein quality in breakfast cereals over the past ten years, and some interesting data on the subject are shown in the ensuing tables.

In Table 1 are given data on protein composition of five cereal grains and some products made from them.

TABLE 1

Total Protein in Various Cereal Products

(Moisture-free basis)

Product	Total Protein*	
	Mean	Range
	%	%
Barley, whole	14.2	12.8-15.6
Barley, pearled	11.3	7.2-15.0
Corn, whole	10.6	8.9-12.2
Corn meal, degermed	9.3	6.8-10.5
Oats, rolled	18.3	15.9-20.4
Rice, brown	9.0	6.9-10.2
Rice, polished	7.8	6.1- 9.7
Wheat, durum	14.4	13.2-16.0
Wheat, hard spring	12.3	11.2-14.1
White flour from hard wheat	11.5	10.3-12.4
Farina from hard wheat	11.2	10.2-12.8
Wheat, soft winter	11.9	11.4-12.8
Wheat, soft white	10.3	6.9-12.3

* Determined by A. O. A. C. method. N × 5.70 for wheat, wheat-flour, farina; N × 6.25 for others.

Of the breakfast cereals, rolled oats contain the highest quantity of protein, followed by farina from hard wheat. Degerminated corn meal is low in protein, and polished rice is lowest.

As is well known, milled products are inferior in protein quality when compared with the grain from which they are made. In Table 2 this is shown in corn meal and farina. The decrease in quality occurs as a result of the removal of the superior quality protein in the germ and outer layers of the grain. However, rolled oats and rolled wheat are exceptions since they are made from whole grain with only the chaff removed.

TABLE 2

Growth Promoting Value of Proteins as Determined in Rat Feeding Tests

Protein Ingredient of Ration	Protein Level	Weight Gain	Ration Intake	Nitrogen Efficiency*
	%	g.	g.	
Dried whole egg	10	131	400	20.2
Lactalbumin	10	124	404	19.2
Dried whole milk	10	110	375	17.9
Casein	10	96	351	16.1
Rolled oats	10	73	341	12.8
Hard wheat	10	37	294	7.7
Farina	9.4	18	220	5.4
Dried whole egg	8	114	387	22.9
Dried whole milk	8	75	318	18.7
Rolled oats	8	53	327	12.6
Whole rye	8	45	317	11.2
Pearled barley	8	29	271	8.3
Whole barley	8	30	290	8.0
Whole corn	7.6	16	230	5.4
Corn meal	7.8	23	181	0.9
Casein	6.6	41	275	13.9
Rolled oats	6.7	29	246	10.7
Polished rice	6.5	23	248	9.1

* Grams gain in body weight per gram of nitrogen consumed.

Decreased protein quality also results from heat processing, the extent depending on the severity of the heating process. For example, merely cooking rolled oats in boiling water does not impair the protein quality. This is shown in Table 3. If there is any difference, it is

TABLE 3

*Growth-Promoting Value: Cooked vs. Uncooked Rolled Oats**

Rat	Sex	Rolled Oats Ration		Cooked Oatmeal Ration	
		Body Weight Gain	Protein Efficiency	Body Weight Gain	Protein Efficiency
		g.		g.	
1	Male	40	1.05	46	1.19
2	Male	42	1.10	49	1.26
3	Male	51	1.34	48	1.24
4	Female	41	1.08	47	1.21
5	Female	39	1.03	41	1.06
6	Female	47	1.24	45	1.16
		Mean	1.14	Mean	1.19
		Relative	100	Relative	104

* Data from Table 1 of Stewart, Hensley, Peters, J. Nutrition *26*, 519 (1943). Results of 56-day test with ration intake of animals of both groups restricted to 388 g.

in favor of the cooked product. We suspect that this is true also of rolled wheat and farina.

Boiling in water is a much less severe heat treatment than toasting and puffing of cereals. Work done in our laboratory and by others has shown that puffed oats may lose 75 percent of their growth promoting value. It should be pointed out, however, that there is no loss of protein quantity in heat processing. In other words, there is no loss of "Kjeldahl nitrogen."

Heat may destroy some of the amino acids, or it may make the protein more resistant to enzyme hydrolysis. Table 4 presents a comparison of the amounts of the amino acid lysine made available as between acid hydrolysis and enzyme hydrolysis during various stages in the manufacture of a ready-to-eat oat cereal. Less lysine is obtained with enzyme hydrolysis than with acid hydrolysis as heating becomes more drastic and, furthermore, the decrease in availability of lysine shows good correlation to the decrease in nitrogen efficiency as indicated in rat growth tests. When lysine is added to the final product the growth value is restored, but not to the same extent as would be predicted from the microbiological lysine assay.

Table 5 indicates that, with exploded oats, the lysine loss may be even greater. Although the addition of

TABLE 5

Supplementation of Oats and Gun-Exploded Oats with Excess Lysine
(Average 14-day results of rat feeding tests; 6 rats per group.)

Protein Fed	Weight Gain	Ration Intake	Body Weight Gain Per		
			100 g.	Ration	Intake
	g.	g.		%	%
Unprocessed oat groats					
Sample	26.0	129	20.0	100	100
Sample + Lysine	28.0	119	22.6	113	113
Exploded oats, light treatment					
Sample	7.3	101	7.2	100	36
Sample + Lysine	17.5	108	16.3	226	82
Exploded oats, severe treatment					
Sample	—1.0	82	—1.3	.....	Neg.
Sample + Lysine	8.3	86	9.1	.....	46

lysine to exploded oats in rations fed to rats results in striking improvement of its growth promoting value, it is not completely restored to the value of unheated oats. This suggests that either the gross digestibility of the proteins of exploded oats is impaired or that other amino acids besides lysine may be destroyed or made less readily available. Table 6 shows the effect of puffing on the apparent change of the ten "essential" amino acids, as determined by hydrolysis. Significant losses of lysine are shown in both light and severe treatment, while significant loss of arginine is shown in the severe treatment.

The cereal technologists' problem here is to find how to make palatable ready-to-eat cereals with a minimum of heat damage to protein. An alternative is to supplement the cooked product with amino acids, particularly lysine. This latter amino acid is now available in quantities suitable for experimental purposes.

Many of the subjects mentioned in this rather brief discussion could be made the topic for a whole paper.

TABLE 4

Some Effects of Heat Processing on the Proteins of an Oat Dough
(Values for lysine are given in percent on a 16.0% N basis)

Sample	Microbiological Lysine Assays				Rat-Growth Tests		
	Total Lysine				Average Daily Ration Intake	56-Day Nitrogen Efficiency**	
	Acid Hydrolysis		Enzyme Hydrolysis				
	%	*Relative*	%	*Relative*	g.	g.	*rel.*
Uncooked Dough	4.5	100	3.6	100	9.6	11.6	100
Cooked Dough	4.5	100	3.2	89	9.6	10.6	91
Toasted Product	3.7	82	2.3	64	6.8	7.0	60
Toasted Product plus Lysine	5.6*	124	4.2*	117	9.6	12.8	110

* Calculated: Lysine found in flakes plus added free lysine. ** Grams gain in body weight per gram of nitrogen consumed.

TABLE 6

Effects of Gun Exploding on the Amino Acid Composition of Oats
(Results calculated on a 16.0% basis)

Amino Acid	Exploded Oats, Light Treatment		Exploded Oats, Severe Treatment	
	Apparent Change	Odds in Favor That Loss Is Significant	Apparent Change	Odds in Favor That Loss Is Significant
Lysine	−23	Greater than 100:1	−34	Greater than 100:1
Arginine	− 6	Less than 20:1	−13	Greater than 20:1
Histidine	+ 2	Less than 20:1	− 4	Less than 20:1
Methionine	−11	Less than 20:1	− 1	Less than 20:1
Leucine	− 4	Less than 20:1	− 1	Less than 20:1
Iso-leucine	− 8	Less than 20:1	− 7	Less than 20:1
Valine	− 5	Less than 20:1	− 5	Less than 20:1
Threonine	− 8	Less than 20:1	− 4	Less than 20:1
Phenylalanine	− 6	Less than 20:1	− 4	Less than 20:1
Tryptophane	− 9	Less than 20:1	−13	Less than 20:1

Rancidity development and flavor problems in the shelf life of cereals have not been discussed, but are problems of the cereal processor. It is hoped, nevertheless, that the foregoing survey of some of the problems involved will stimulate interest in the field of breakfast cereal technology.

Some Problems In the Manufacture of Hard Candy[a]

A. B. CRAMER
F & F Laboratories, Chicago, Illinois

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REVIEW PAPER

Some of the major factors influencing hard candy quality and shelf life are discussed together with control measures which will aid in the manufacture of high quality hard candy.

Keeping quality or shelf life is one of the most important problems facing the hard candy technologist. To no small degree this is a problem of packaging and from a practical viewpoint the packaging should be looked upon as a concomitant of the candy's quality. However, aside from the question of packaging, the candy should have certain intrinsic properties which may be considered as the mainstays of quality. The question, therefore, arises what is meant by "Quality" in hard candy?

To some extent, quality requirements depend on the eventual function of the candy. In our laboratories, for instance, candy to serve two distinct and different functions is manufactured. For lozenges, a candy base which is specifically designed for that purpose is used. For obvious reasons flavor, and flavor response, are here not major considerations. On the other hand, as the candy is to be held in the mouth for some time, it must dissolve so as to always present a smooth, even surface to the palate and tongue. Also of particular importance is the rate of solution. As a medium of medication requiring prolonged action, a slow solution rate of the candy in the saliva is highly desirable if not absolutely essential.

Quite a different set of characteristics are required of fruit-flavored hard candies. These being purely confections, appearance and flavor are paramount. For aesthetic purposes, wherever possible, the candy should be bright and sparkling in color with a high degree of transparency. The latter property has importance not only from aesthetic considerations, but because clarity is most frequently associated with purity. As a component of flavor, texture has also a prominent position. Here, as with the lozenge, a smooth, even, almost slick surface maintained throughout what might be called its "mouth life" is most sought for. Unlike the lozenge however, the fruit candy must have a rapid flavor response. The sense of taste must be stimulated almost at the instant the candy is put in the mouth. This requires not only high solubility, but a rapid solution rate.

One other point common for the two types should receive particular emphasis because of its profound effect on shelf life. This is the hygroscopicity of the candy. A highly hyroscopic hard candy will automatically cancel many of the other qualities within a very short time, no matter how carefully they have been incorporated into the product. Not only is a wet, sticky, surface on the candy repulsive (it has been referred to as "pre-licked") but with it is associated the loss of many of those other qualities which were so painfully instilled.

The technologist must thoroughly understand what is involved in each of these quality points if he is to deal effectively with the problem of shelf life. It should be realized that many of the difficulties associated with the manufacture and preservation of hard candy are due to its metastable state. Hard candy is essentially a glass composed of a mixture of fused carbohydrates. As such, it has an everpresent tendency to return to the more stable crystalline state. What is meant by this can be best demonstrated by attempting to concentrate a pure neutral sugar solution to a moisture content of less than 1 percent. The result is inevitably the complete crystallization of the sugar mass. Not only is such a product undesirable because of texture, but it is completely unworkable in any of the standard processes designed for

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flavoring, coloring, and shaping of the candy. This tendency to crystallize is known to the candy man as "graining," and is perpetually a threat both to the smooth flow of production and to the basic quality of the candy.

Graining, and tackiness due to hygroscopicity are probably the two most virulent enemies of good shelf life in hard candy. Almost anybody who has ever purchased hard candy is familiar with the grained product. The original lustrous surface has been replaced by a dull opaque coating and the bright sparkling colors are usually transformed into mottled pastels with their initial sparkle and clarity completely destroyed. Finally, the smooth, hard, even texture has given way to a softer, sometimes mushy, grainy texture that bears no resemblance to the original product. In short, the candy conveys the clear impression of stale and inferior merchandise, an impression that is by no means unjustified. In addition, other subtler changes may have also occurred. The hard candy in good condition provides a hermetically sealed medium for the flavor elements dispersed throughout it. With the formation of grain the exact reversal of this situation has taken place. Not only does the coarse open structure of the grain expose the flavor, but by its capillary action tends to draw the flavor elements to the surface exposing them to evaporation and oxidative changes which may have a profound effect on them.

The type of grain just described is the one most familiar to the casual buyer. Although its speed of formation and the rapidity with which it transforms the mass may vary with the intrinsic properties of the candy, it is nevertheless to be expected in all hard candy. The actual gauge of quality lies in the time the candy can be held before the onset of this graining occurs and the time it takes to spread throughout the candy. This time element is related to the initial quality of the candy. This brings into consideration a second type of graining which is a direct product of the manufacturing process. This type of graining may often be so slight as to be completely unnoticeable in the fresh candy. It may also vary all the way from this incipience up to a degree that gives the candy the texture of cemented sand. In this type of grain the crystals of sugar, instead of being confined to a gradually thickening outer skin, are spread throughout the body of the candy. As intimated, the effect on initial texture can be disastrous. The effect on shelf life is equally malignant, as the well dispersed crystal nuclei can do much to aid and abet the growth of the more common surface grain with which we are more familiar.

To combat grain, the candy man resorts to what he calls a "doctor." Broadly speaking, a doctor may be defined as any material, which when added to the candy prior to or during cooking, will act to inhibit or prevent crystallization. Included among such materials are corn syrup, invert sugar and acidic reagents such as cream of tartar which will act to form invert sugar from the cane or beet sugar. In the use of such doctors the candy maker is simply applying the principle well known among chemists that the addition of other substances will inhibit crystallization.

It is in the proper control of these doctors that the technologists' chief problems arise. An excess of doctor will cause undesirably high hygroscopicity, whereas a deficiency will give rise to a susceptibility to graining. The problem is further complicated by the fact that the doctor usually serves a multiplicity of purposes. Thus, corn syrup is of importance not only as a doctor, but for obvious economic reasons. Costing anything from one-half to three cents a pound less than sugar (on a solids basis), the candy maker is naturally anxious to use as much as he can without a sacrifice of quality. Cost alone, however, is not the only criterion. The lower solubility of the corn syrup solids is an important factor in governing the solubility rate of the finished candy. Furthermore, its lesser sweetening power may also be an important consideration in flavor design. Unfortunately, most of the advantages enumerated may be offset by certain disadvantages. High on this list is the high hygroscopicity imparted to the candy by a high corn syrup content. Associated with this is a general tendency toward stickiness, a kind of cold flow plasticity which is not related to the moisture content and which is generally undesirable. The lower rate of solubility, although a valuable adjunct in the formulation of a cough lozenge, is a definite disadvantage where rapid flavor response is desirable. Finally, as may be well imagined, the lower sweetening ability may act more frequently to the detriment than to the advantage of a confectionery product.

Invert sugar, as a doctor, acts very much like corn syrup but certain other of its properties stand out in marked contrast. Much more rapidly soluble than corn syrup, it serves admirably where a high, fast flavor response is desired, as with most confectionery products. To a degree it serves to reinforce this action by a sweetening power that is appreciably higher than that of corn syrup. Also, unlike corn syrup, invert sugar does not seem to have the plasticising effect of corn syrup. This may act either as an advantage or disadvantage. As a property present in excess, the plasticity imparted by corn syrup may tend to cause what amounts to a cold flow, resulting in the sticking and agglomeration of the most carefully protected products. A candy in which the doctor is largely or entirely invert sugar, may tend to show a marked brittleness and fragility. This will result in candy marred by chips and broken fragments unless the most careful precautions are practiced. Finally, comparatively slight variations in the proportion of invert sugar are apt to have a far more profound effect on the candy than is the case with corn syrup. In but slight excess, the former will cause a most marked hygroscopicity which may defy all but the most rigid packaging specifications. If, in contrast, the invert sugar falls but slightly below certain limits, the tendency for incipient graining becomes pronounced and both initial quality and shelf life are correspondingly lowered.

It is evident that by carefully weighing the inherent properties of each type of doctor, it should be possible to formulate hard candies with widely varying properties. Thus the judicious use of corn syrup, invert sugar, and beet or cane sugar, all properly balanced, should produce a candy perfectly tailored to one's needs. Were

it only necesary to weigh or measure each constituent in its proper proportion into the candy kettle, the problem would be simple. All that would be necessary would be a proper monitoring of scales and meters and adjustment of these instruments wherever and whenever necessary. Unfortunately, the answer is never quite so simple. As the sugar technologist knows only too well, almost anything you do to a sugar solution alters it. Particularly true is this when the solution is acidic as in the usual candy cook.

When a more or less acidic solution of sugar (sucrose) is heated to boiling, inversion will always occur. This product obtained by inversion during cooking is referred to as "cooking invert" and may vary widely depending on the raw materials, the equipment, and how the latter is used. It is the control of this variation in the cooking invert that will make the difference between poor and good candy and between long and short shelf life. As cooking invert must be expected, it must also be allowed for in the candy's formulation. Over, or underestimation of the extent of inversion which will occur results in a corresponding variation in the final product with the consequences already described.

The problem, therefore, becomes one of maintaining cooking conditions so that the degree of inversion will be kept within reasonably narrow limits. As has been implied, this means study of the raw materials, the equipment, and of the processing procedure.

On the question of raw materials, it is most difficult to lay down any rules. Inversion is a reaction greatly affected by acidity (pH). However, candy cooking is a process taking place over a prolonged period at an elevated temperature and, in addition, is a process of concentration. Thus, an acidity which may be a negligible factor at the initial concentration and temperature, may give rise to marked changes in the product that is removed from the candy kettle. It is because of this that the apparently relatively minor factors of water hardness, and sugar ash assume such large proportions in the candy technologists' eyes. For the most part the water may be allowed for in the initial formulation and then forgotten, as it is usually fairly constant in its effect in any given area. Such, however, is not the case with sugars, which will vary widely in their behavior in the cooking kettle. Despite their extraordinary purity, the very small percentages of ash present play a major role as buffering agents. Some sugars will pass through the cooking process with relatively little inversion because their ash has a desirable buffering effect. Others may undergo several percent higher inversion than is usual, giving rise to the difficulties already described. This effect may in part be neutralized by addition to the cook of very small amounts of buffering salts, such as soda ash. Where this is done, extreme caution must be observed as the cure may well be worse than the disease in the side effects which are generated. Hence, it is a practice to be recommended only in the most extreme cases.

Frequently the action of the corn syrup with its buffer reserve is extremely valuable in the control of kettle conditions. The manufacturer of corn syrup is usually willing and able to meet specifications as to pH and this, along with the natural buffering effect of the corn syrup, is of enormous assistance in the control of the product.

Where the manufacturer converts his scrap to invert for use in his own formulation, he has another means of control. By regulating the pH of the invert syrup he may, from time to time, compensate for vagaries in the sugar. At our laboratories this has been found to serve ideally as an inversion regulator, and has provided the solution to a problem that could otherwise be at best only partially solved.

In discussing equipment it is also difficult if not impossible to lay down any general rules. There is a wide variation in the types of cookers in use, and in their application. Of course, the formula must be suited to the cooker. For example, a low corn syrup, low invert formula cannot be cooked in a continuous vacuum coil process. Any attempt to do so will sooner or later result in crystal choked coils, yielding candy which in texture will more closely resemble an abrasive than a confection. Similar considerations will enter into the use of other types of cookers, and each must be studied with care for its own particular cooking characteristics.

Closely associated with both the equipment and processing technique is the entire problem of instrumentation and automatic controls. Any man who has ever attempted to set up and maintain quality standards in processing must soon come to realize that his process is highly susceptible to the human element, the operator. With the best will in the world, minor variations in processing (the so-called personal factor) will tend to creep in unless careful supervision is maintained at all times. To avoid or minimize this effect, wide use is made in our laboratories of continuous recording charts, and wherever possible, of automatic control. It is difficult to overemphasize the importance of this feature in modern candy cooking. Frequently it is not necessary to install automatic controls along the entire production line. If the process is well integrated and carefully scheduled, the automatic regulation of one phase of the process will force the operator to synchronize the rest of the process with the controlled area. The knowledge that his timing and temperature controls are subject to inspection by means of the recording chart will do much to keep the operators from deviations from prescribed procedures.

Finally, reference must be made to two of the most important indices of process and product uniformity, reducing sugar, and moisture. The reducing sugar content of a candy, in conjunction with organoleptic tests, can give the technologist much information about any hard candy, and almost a complete synopsis of his own products history. As a gauge of the degree of cooking inversion it is an invaluable tool. If the texture of the product is right and the reducing sugar and moisture are within the prescribed limits, he needs no plant inspection to tell him that all is going well in the factory. If the texture is rough and the reducing sugar is within limits, in the majority of cases he may expect a high moisture. Under such circumstances an inspection of temperature charts and vacuum seals and pumps becomes an immedi-

ate necessity. A low reducing sugar with a poor texture will indicate inadequate cooking inversion, and readjustment of the pH of the cook by one of the means already outlined will be required. A high reducing sugar will indicate excessive inversion and may mean excessive cooking time, or temperature, or low pH. Here again, inspection of the charts may provide a solution. If the inspection shows no violation of schedules then readjustment of pH must again be considered.

Although important in itself moisture content may also be of great value as a diagnostic tool as an indication of keeping quality. Certainly a candy with a moisture content in excess of 1 percent can be expected to have a very poor shelf life. In addition, under certain conditions a high moisture may be expected to foster graining, both during processing and on aging. For this reason moisture content must be watched as closely as the reducing sugar. As already mentioned, it may be used as a gauge to indicate the rigidity with which the operator is following cooking schedules and as a measure of the general efficiency of the cooking process.

Enough has been said about reducing sugar and moisture to indicate their importance as routine control analyses. Applied intelligently as monitoring devices, they can be used with considerable success in maintaining uniform quality and good shelf life. This is not to be taken to mean that these or any other analyses are adequate substitutes for good supervision. Control procedures merely act to assist and reinforce supervision and at times to forecast trouble before even the most careful supervisor can hope to detect it. This, after all, is the most that can be expected of any control procedure, and if it does this well, it needs no other argument to justify itself.

In the preceding discussion, the subject has been carefully restricted to a consideration of the hard candy base. No attempt has been made to include the many other aspects that must be considered when the final quality of the finished goods is being assessed. Thus, the large and important fields of flavor, color and packaging have been deliberately ignored. This has been done not through any lack of recognition of their significance, but rather out of a complete recognition of their extreme importance. Each embraces a full field of technology of its own, and it was felt that in this paper merely to touch on either subject would be both imprudent and impudent. For these reasons the field of discussion was restricted with the hope that in so doing, an understanding of one problem rather than a smattering of many could be achieved.

Methods of Measuring the Tenderness and Maturity of Processed Peas

RACHEL U. MAKOWER
Western Regional Research Laboratory,[a] Albany, California

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REVIEW PAPER

In peas the organoleptic quality known as "maturity" is measured most directly by trained human judges. The Tenderometer for raw peas and alcohol-insoluble solids for processed peas are the best objective methods. Other less adequate methods and the need for further methodological research are discussed.

Introduction

During the ripening of fresh green peas *(Pisum sativum L.)*, there is a stage when the eating quality of the vegetable is optimal; that is, flavor and texture are best. Before this time the peas are small and very tender but lack full flavor; after this time, they become tough and starchy. It is to the advantage of both processor and consumer to obtain raw material at a stage of maturity which results in a product of the best possible quality.

The term "maturity" usually refers to some stage in the development of an organism or organ. However, to the consumer of processed peas, it denotes a strictly subjective characteristic involving succulence or starchiness and tenderness or toughness of the peas. This fact was recognized in the use of the terms "maturity" *(95)* and "tenderness and maturity" *(96)* in the United States standards for grades of canned *(95)* and frozen *(96)* peas where these terms refer to a quality essentially textural. The use of the term "maturity" to describe an organoleptic quality may not be universally acceptable. In this review, however, the terms "maturity" or "tenderness and maturity" will be used to describe this textural quality in peas.

The tenderness and maturity of a given sample of processed peas will depend largely on the physiological maturity of the raw vegetable which in turn is determined by genetic, geographic and climatic factors.[b] However, subsequent conditions of harvesting, handling and processing may also influence the final maturity of the product, especially if measured organoleptically, that is, by a panel of human judges.

The measurement of "maturity" of frozen peas is the subject of a current project at this Laboratory. In con-

[a] Bureau of Agricultural and Industrial Chemistry, U. S. Department of Agriculture, Albany, California. Report of a study made under the Research and Marketing Act of 1946.

[b] Pea varieties differ in their suitability for freezing *(24, 27, 28)*, composition and edible quality *(30, 86)*, and toughness or tenderness *(21, 31, 36, 48, 64, 72, 82)*. Geography and climate often determine what varieties can be grown and how fast they will mature *(6, 18, 22, 31, 44, 78, 80, 81, 84)*. With the same variety of peas, the rate of maturation varies with locality *(36)*, season *(84)*, temperature *(6, 22, 81, 84)* and soil conditions *(44, 77, 80, 82)*.

TABLE 1

Methods Widely Used for Measuring "Tenderness and Maturity" in Peas

Method	Principle	Material and Treatment	Major Advantages and Limitations*
A. Organoleptic appraisal	Grading by trained panel of human judges	Cooked peas (previously raw or processed)	Primary standard. Expensive, time consuming, not yet standardized.
B. Objective methods 1. Brine flotation test —USDA	Density of pea cotyledons	Frozen or canned peas. Cotyledons only	Rapid, basis for official grades. Quality of skins excluded.
2. Size	Separation on standard sieves	Raw peas only	Easily applied. Influenced by harvest date and variety. Not reliable.
3. Tenderometer	Shearing and crushing	Raw peas	Rapid and reproducible. Does not reflect subsequent toughening. Appears to be unsuitable for frozen peas.
4. Density and specific gravity	Density of whole peas	Frozen or canned peas	Fairly rapid. Influenced by air under the skins. Does not reflect toughening of skins.
5. Alcohol insoluble solids	Weight of dry solids after extraction with alcohol	Raw or processed peas	Correlates well with A. Time consuming. Influenced by desiccation.
6. Total solids (dry matter)	Weight of dry matter	Raw or processed peas	Correlates fairly well with A. Time consuming. Easily influenced by leaching and desiccation in processing and storage.
7. Starch	Quantity of starch	Raw or processed peas	Measures a primary factor. Accuracy varies with method. Time consuming. Influenced by desiccation.
8. Sugars	Quantity of total sugars	Raw or processed peas	No advantages. Easily lost in processing. Not directly related to maturity.

* See text for detailed discussion.

nection with this project, we have found it necessary to review published obesrvations on this subject. This compilation is being presented with the thought that it would be useful to other workers in this field.

The literature on maturity of peas is extensive, but much of it is very general and repetitious. Sometimes conclusions, apparently based on experiments, are presented without the experimental evidence to support them. Such publications, largely intended for the non-technical readers in the food industry, are extremely difficult to evaluate. The frequent reprinting of articles by different trade journals, sometimes under different titles, is also confusing. We have attempted here to list the main sources of information on methods for measuring the maturity of peas.

Influence of Handling and Processing on the "Maturity" of Peas

Peas of all sizes toughen day after day when left in the field *(1, 14, 78)*. This toughening is faster at higher temperatures *(22, 77, 84)*. Harvest delays of a few days in warm weather may result in tough and greatly overmature peas *(22)*.

The skin texture of peas is influenced by various conditions of treatment after harvest. The skin of peas may toughen appreciably due to conditions of treatment, such as blanching in hard water *(10, 34, 41, 57, 65, 68)* or bruising and holding (delay) between vining and processing *(15, 27, 33, 34, 35, 50, 52a, 63, 71)*. It appears that peas with tough skins are characterized by an increased calcium content *(6, 33, 34, 50, 65, 82)*. With increasing maturity, the calcium in pea skins increases *(17, 52b)*, while phosphorus decreases *(17)*. The toughening of skins due to hard water may be prevented or remedied to some extent by treatment of blanching water with sodium hexametaphosphate *(40, 68)*. This process presumably decreases the calcium content of peas. However, careful control of concentration is necessary to avoid undesirable effects *(40)*. Differences in the rate of freezing also appear to influence the texture of peas *(32)*.

Methods for Measuring "Tenderness and Maturity"

As stated above, "maturity" in peas is essentially a subjective quality, which can be measured directly only by a panel of human judges, that is, by the method of organoleptic appraisal. Any objective method for measuring maturity must necessarily depend on comparison with the basic subjective method. The techniques of organoleptic appraisal have not yet been standardized and are subject to considerable variation due to psychological and other factors which enter into such judgments. However, unless the results of a given objective method are in close agreement with organoleptic appraisal of the same material, the objective method cannot be considered reliable. The most important methods for measuring maturity in peas and some of their characteristics are listed in Table 1.

Comparisons of these methods are very difficult. Studies including the degree of correlation between a given objective method and organoleptic tests on the same material are, unfortunately, very few, particularly on frozen peas *(69)*. The procedures and methods of organoleptic appraisal differ widely.

The great majority of objective methods give an average value for the quality measured in a given sample of peas. A sample may be made up of peas highly uniform as to maturity or it may contain both immature and overmature peas. Most objective methods fail to measure the disproportionate lowering of organoleptic quality caused by the presence of a small fraction of tough peas. An objective method, such as alcohol-insoluble solids, based on average values, will not show the presence of the overmature peas, if enough undermature peas are present to compensate.

At present, only two methods are in use which detect and perhaps estimate the overmature portion of a sample of peas. One of these is the subjective method of organoleptic appraisal; the other is the objective brine flotation test used for the grading of tenderness and maturity according to the United States standards for grades of frozen and of canned peas (employed by

the U.S.D.A. inspectors). It will be seen later in the discussion of these methods that they do not always correlate well with each other.

A. Organoleptic Appraisal

Organoleptic appraisals by panels of human judges have been made by many workers *(1, 2, 6, 15, 28, 48, 58, 69, 71, 82, 83, 98)* on cooked peas. The maturity of either the whole peas or the skins and cotyledons separately were evaluated by this basic subjective method. As peas ripen, their skins toughen *(14, 15, 78)* and their cotyledons become more firm *(74, 78)*. This toughening is reflected in higher Tenderometer values of the raw peas as well as in the subjective scores of the processed and cooked product *(1, 15, 54, 69, 74)*.

The published appraisals do not always list the size and variety of peas used, size and training of the panels, the number of samples per tasting or the number of replicate tastings. When indicated, these factors vary greatly from study to study, making comparisons difficult. Variability in cooking conditions may also occur and influence the reliability of this method. A good review of organoleptic appraisal methods has recently been published *(16)*.

The difficulties of this method are due to inherent variability of human judgments and the necessity for statistical techniques, which involve time-consuming and expensive procedures. This method requires basic research in methodology and standardization of techniques. Nevertheless, organoleptic appraisal remains the ultimate reference method for the determination of organoleptic quality factors of food, including the tenderness and maturity of peas.

B. Objective Methods

1. *Brine Flotation Test—U.S.D.A. Method.* The proportion of peas that sink in a given concentration of brine (13, 15 or 16% NaCl) forms the basis for the present United States standard grading procedure for maturity of canned *(95)* and of frozen[c] *(87, 96)* peas. The advantages of this method are speed and the ability to estimate the most mature portion of the sample, rather than an average of the whole sample.

As compared with organoleptic appraisal, Lee found the brine flotation test a less accurate index of maturity than some of the other methods (alcohol-insoluble solids and specific gravity) *(54)*. He recommends the rapid direct measurement of specific gravity of thawed peas *(54, 55)*. Likewise, the studies of Nielsen et al. on several varieties of peas grown in two localities for two seasons indicate that the percentage of sinkers in brine does not correlate well with the results of other methods for measuring maturity *(69)*.

Muenchow studied the distribution of the United States standard tenderness and maturity scores (brine flotation test) against Tenderometer readings. The thawed frozen peas for the same grade in the fancy (A) grade level had raw pea Tenderometer readings from 70 to 113; those in the B grade level from 85 to over 125 *(66)*. Comparable results were obtained by Martin et al. *(63)*. As the Tenderometer is usually considered a reasonably good measure of maturity of raw peas *(69)*, the method used for the determination of the United States standard grades would appear to be a poorer measure of maturity. Both these studies *(63, 66)*, as well as some others *(1, 7, 28, 69, 85)* show inadequate correlation between sinkers in brine of the frozen peas and the Tenderometer readings of the original raw peas.

2. *Size of Peas.* That the size of peas is not a reliable index of maturity is demonstrated by various studies *(2, 14, 15)*. The maturity of a given size depends on the variety of the peas, the location and conditions of harvesting and other factors *(15)*.

3. *Tenderometer and Other Mechanical Methods for Measuring Texture.* The Tenderometer is a mechanical apparatus widely used in the vegetable processing industry for evaluating the tenderness and maturity of raw peas *(54, 61, 63, 98)*, but it has not been commonly used with processed peas *(53)*. Numerous studies have been carried out which correlate the Tenderometer values on raw peas with other measures of maturity, such as the subjective scores of judges *(25, 28, 69, 83, 98)*, alcohol-insoluble solids in canned peas *(51, 52, 53, 54, 63, 99, 100)* and in frozen peas *(52, 54)*, as well as total solids in canned and in frozen peas *(20, 69, 75)*. All these correlations appear to be relatively good, especially when uniform material from one locality and a single Tenderometer have been used throughout a study. The measurement of alcohol-insoluble solids of raw and canned peas has been suggested as a method for the standardization of Tenderometers *(52)*; on the other hand, there is evidence of variability in the determinations of alcohol-insoluble solids of frozen peas *(53)*. Recently, standard samples of peas preserved in alcohol have been made available for the calibration of Tenderometers *(94)*. However, Tenderometer values for raw peas correlate only fairly well with the U.S.D.A. method for measuring the maturity of frozen peas *(1, 2, 66, 69)* or with specific gravity *(53, 54, 69)*. The Tenderometer values, in spite of considerable variation *(53, 55, 63)* are in much better agreement with the U.S.D.A. method for canned peas *(1, 2, 54, 63)*.

The Tenderometer readings have been subject to error from variation among instruments and, until recently *(94)*, from a lack of an adequate standard for adjusting the mechanism. Environmental factors such as temperature also contribute to errors *(26, 28, 63)*. A temperature correction has been suggested *(28)*, but the relationship between Tenderometer readings and the temperature of the peas is not a simple one *(63)*. In general, the higher the temperature the lower the Tenderometer reading *(28)*. At present, the Tenderometer is used to measure the toughness of raw peas; any subsequent toughening in processing or storage is therefore not revealed by the Tenderometer values. The Tenderometer gives less than adequate results with blanched, canned, or thawed frozen peas *(53, 54)*.

Among other mechanical methods for measuring the texture of peas, the Texturemeter has been used *(54, 101)*. The Penetrometer *(8, 15, 29)* can be used to measure the toughness of the skins and the cotyledons

[c] In the grading of frozen peas only the cotyledons are tested in brine. A modification of this test which obviates the laborious peeling of the peas has been developed and will be described in a forthcoming paper *(102)*.

separately. A modified smaller model of the Tenderometer has also been suggested *(51a, 52a)*. Mechanical puncture methods have been used *(6, 41, 82)* as well as crushing methods *(1, 2, 19, 41, 82)* Most of these methods have few apparent advantages over the Tenderometer, while others are too new for critical evaluation *(52a, 79)*.

A good mechanical test for pea texture should correlate closely with organoleptic appraisal of texture or maturity and therefore should measure the increased starchiness of the more mature pea as well as the skin toughness. In general, mechanical methods of measuring toughness by crushing *(1, 2)*, mechanical puncturing *(15, 19, 82)* and shearing with the Tenderometer *(54, 69)* correlate relatively well with organoleptic appraisal of maturity.

4. *Specific Gravity and Density.* Specific gravity (or density) of peas increases as ripening proceeds. Several methods have been used to measure the average specific gravity of peas *(42, 43, 54, 55, 56)*. Specific gravity appears to be a fair measure of maturity; that is, it correlates fairly well with organoleptic tests *(54, 55)*, but it is probably not as reliable as total solids *(1, 2, 43, 69)*, or alcohol-insoluble solids of canned peas *(1, 2, 56)* or even as the Tenderometer with raw peas *(66, 69)*. The last three methods have been shown to correlate fairly well with organoleptic estimates of tenderness and maturity *(54, 55, 69)*.

Most measurements of average specific gravity given in the literature are subject to two important errors: the buoyancy of the air present in the whole peas (where the skins were not removed) and the changes in specific gravity in both the peas and the surrounding liquid during the measurements. These errors enter likewise into the quality separation by specific gravity of blanched peas carried out in processing *(5, 23, 37, 90, 97)*, though other factors may also interfere *(23, 28, 60)*. The leaching out of sugar and other nutrients from peas during processing is well recognized *(4, 23, 59, 92)* and may appreciably change the density of the peas. On the other hand, the absorption of salt by the peas resulting in increased density goes on at the same time *(23)*.

5. *Alcohol-Insoluble Solids.* Solids insoluble in ethyl alcohol steadily increase with the ripening of the peas. In canned peas, the percentage of alcohol-insoluble solids has long been considered a reliable measure of maturity *(1, 21, 36, 47, 48, 49, 51, 52, 53, 90, 100)*. The United States Federal Food, Drug and Cosmetics Act requires the analysis of canned peas for alcohol-insoluble solids *(9, 95)*; this analysis has become a part of the United States standard for grades of canned peas *(95)*.

Kertesz considers alcohol-insoluble solids a better measure of maturity for canned peas than total solids, in spite of a considerable overlapping of U. S. standard grades for the same alcohol-insoluble solids values *(47)*. This overlapping of grades is likely to be even greater with peas of different varieties and from various localities. Strasburger *(90)* and Bonney and Rowe *(21)* found that the percentage of alcohol-insoluble solids is a good index of maturity. Walls and Kemp *(100)*, Kramer *(51, 52)*, and Lee *(53, 54)* found a high correlation between alcohol-insoluble solids of canned and frozen peas, and tenderometer value of raw peas, though Lee encountered great variability with the thawed frozen material *(53)*. In frozen peas, errors due to dessication are seldom mentioned. In most of these studies materials from a limited number of varieties and localities were used. Poorer correlations might have been found if peas of several varieties, seasons, and widely scattered localities had been used in a single study.

6. *Total Solids (Dry Matter).* As peas mature, the percentage of solids or dry matter steadily increases *(11, 12, 45, 90)*. Strasburger *(88)* and Bonney and Palmore *(20)* recommended total solids as an index of maturity in canned peas, though Kertesz considered this method somewhat inferior to alcohol-insoluble solids *(47, 48)*. A high correlation was found between total solids and other measures of maturity, such as Tenderometer reading, organoleptic appraisal scores and starch content *(69)*. Pyke *(75)* also gave a high correlation coefficient for Tenderometer vs. total solids in peas, while Jodidi found a poor correlation between dry matter and specific gravity of raw peas *(43)*.

However, as peas become more mature physiologically, the amounts of starch, protein and cellulose increase while the sugars decrease. Moreover, the amount of sugar varies not only with maturity, but also with numerous other conditions having no relation to maturity. Therefore, the quantity of total solids is not likely to be as reliable a measure of maturity as the value for alcohol-insoluble solids. Both methods, nevertheless, can be considered as good average measures of the maturity of peas *(2, 69, 89)*. Several other factors may influence the accuracy of total solids as an index of maturity in peas. The moisture content may be influenced by seasonal and harvesting conditions *(3)*, processing *(67, 93)* or storage *(76, 103)*. Desiccation which occurs in processing will increase the percentage of total solids in the frozen product, but since the lost moisture is probably restored in cooking *(91, 96a)*, the organoleptic quality may not be affected. Leaching losses, however, may seriously influence the values for total solids *(4, 59, 92)*.

7. *Starch.* As the amount of starch in peas increases with the ripening of the seed, an estimate of the starch content should be a good measure of the maturity of the pea. That starch is at least a fair measure of maturity has been indicated by Nielsen et al. *(69)*, Adam *(1)*, Pyke *(75)* and Pollard, Wilcox and Peterson *(73, 74)*. However, the determination of starch by Nielsen's method is subject to error because the proportions of amylose and amylopectin may vary in different varieties *(39, 70, 72)* and in the same variety depending upon the stage of physiological maturity of the peas used *(64, 72)*. Not only total starch but the proportion of the amylose fraction increases with maturity *(64)*. Other methods of starch determination are not only laborious, but are also subject to considerable error. According to Hilbert and MacMasters *(39)* and Heiduschka and Tettenborn *(38)*, pea starch has some peculiar physical and chemical properties. This fact might conceivably influence the accuracy of the simplified starch methods. With frozen peas, desiccation may cause additional errors.

8. *Sugars.* The amounts of reducing and total sugars in peas are highly variable and have been shown to be poor indices of maturity *(1, 13, 45, 54, 69)*. Sugars are extremely labile in the living pea before blanching *(6, 12, 46)* and are highly diffusible thereafter *(4, 59)*. Because of the lability of sugar and the fact that in the maturing peas the sugar content first increases and then decreases *(11, 22, 69)*, it is difficult to estimate the maturity of processed peas from the amount of sugar present. Also, leaching losses in processing greatly affect the sugar content of peas *(4, 59, 92)*. The starch-sugar ratio is a somewhat better measure of maturity *(6)*.

9. *Other Objective Methods.* (a) The refractive index of the juice of raw peas was determined by Walls *(97)*. He found no relation between refractometer readings and the maturity grade of the peas. There was a great variation in refractometer readings. Martin and Brotherton *(62)* measured the refractive index, freezing point, and electrical conductivity of pea sap and found them unsuitable as indices of maturity.

(b) The amount of juice in raw peas was measured by Walls *(97)* and found inadequate as an index of maturity. Walls also observed a number of "hard floaters" which were probably overmature peas that had lost weight *(97)*.

(c) Proteins increase with maturity, but vary with variety of the peas. Organoleptic estimates of maturity and Tenderometer reading do not correlate well with the protein values *(69)*.

(d) The lipid content of peas appears quite variable and does not correlate with Tenderometer values *(69)*.

Discussion and Conclusions

From the point of view of the consumer of processed peas the quality known as "maturity" is primarily textural and is influenced not only by the physiological stage of ripeness at which the peas were harvested but also by varietal and cultural factors and by changes which occur during processing. For this reason organoleptic appraisal is the basic standard with which objective tests for maturity must be compared. Unfortunately, organoleptic methods have not been standardized and the techniques that have been used are subject to large experimental errors. Further development of these methods is urgently needed. Some of the tests which might be used to measure maturity have not been compared with organoleptic tests but only with other objective methods. High correlation coefficients were often obtained in studies made with materials uniform as to variety, locality, season and method of processing. But the general applicability of any test for the grading of commercially processed peas may be questioned until good correlations have been found with many samples of processed peas from widely scattered sources.

The literature provides no conclusive appraisal of the value of most methods of measuring maturity, but it is clear that size, refractive index, and the sugar content of peas are not suitable. It has not been fully established whether or not any of the other objective methods or modifications thereof would be satisfactory. Since the non-mechanical tests for density, starch, total solids, and alcohol-insoluble solids reflect the properties of the cotyledons more than of the skins, it seems doubtful that such tests can adequately measure the quality of peas with unusually tough skins. The Tenderometer can probably be considered the best means of determining the maturity of raw peas, but it does not reveal the effects of handling and processing after harvesting. For processed peas, the alcohol-insoluble-solids test is probably the most reliable objective measure of the organoleptic quality known as maturity.

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Problems In Handling Fresh and Frozen Shrimp[a, b]

E. A. FIEGER

Department of Agricultural Chemistry and Biochemistry, Agricultural Experiment Station, Louisiana State University, Baton Rouge, Louisiana

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A resumé is presented of the problems confronting the shrimp industry in its attempts to improve the quality of fresh, frozen and frozen cooked shrimp offered for sale on the retail markets. Modifications in the methods of handling and storing fresh shrimp on board shrimp trawlers, and in wholesale and retail markets are suggested.

In spite of the fact that shrimp are very fragile and require careful handling and processing, only to a limited extent have they been the subject of scientific investigation. In this discussion, problems confronting the shrimp industry will be pointed out and some conclusions given based upon the work conducted in our laboratory.

In handling shrimp, from the actual fishing until delivery to the ultimate consumer, the industry has mostly failed to take cognizance of the losses resulting from careless handling. In shrimp fishing the nets which are towed along the bottom of the sea collect rough fish and shell fish as well as shrimp. Since the net may be towed for two hours or more, it is understandable that some bruising of the shrimp can occur. Crushing and bruising likewise occur during the operation of hauling the net on board the trawler, since the total load may be as great as two to three thousand pounds. After separation of the shrimp from the rough fish and shellfish, the shrimp are either stored on board the trawlers as whole shrimp or are headed and stored as headed shrimp. In Louisiana it is common practice for shrimp fishermen to head shrimp caught during the first part of the trip and store whole shrimp during the latter part. This practice, which resulted from the observation that headed shrimp keep for a longer period of time than whole shrimp, has been confirmed by our observation *(3)* that the bacteria on shrimp occur to the greatest extent on the heads (Table 1). This is somewhat unfortunate since heading is a disagreeable task and consumes time needed by the crew for other duties.

TABLE 1

Bacterial counts of some unwashed shrimp

	No. of bacteria, per gram
Whole Shrimp	42,000
Headed Shrimp	10,000
Slime (from one whole and four headless shrimp)	210,000

Mississippi shrimp fishermen use a different method in handling shrimp. This consists in placing the whole shrimp in baskets and storing on deck until fishing for the day is completed. The shrimp boats then rendezvous in some sheltered bay, inlet or pass where the shrimp are transferred to a so-called freight boat and packed in ice in the hold as described below. The freight boat returns to port to unload after three to four days so that the shrimp are processed within five days after catching. Then another boat in the fleet takes on the duty of being a freight boat. It should be pointed out that standing on deck when temperatures are above 40 to 45° F. (4.4 to 7.2° C.) is not conducive to maintenance of quality shrimp and is a practice that is strongly condemned.

Thorough washing of the whole or headed shrimp before icing on the trawler is a most desirable practice *(3)*. This is carried out with sea water, the usual practice being to dip the shrimp in barrels of sea water, or to direct a stream of water into metal baskets containing the shrimp, or to place them in a wash net and tow it through the sea for five minutes or longer. Efficient washing can reduce the bacterial count as much as 75 percent (Table 2).

TABLE 2

Effect of washing some shrimp on their bacterial counts

	No. of bacteria, per gram
Whole Shrimp—unwashed	42,000
Whole Shrimp—washed	16,000
Headed Shrimp—unwashed	10,000
Headed Shrimp—washed	7,400

After being washed, the shrimp are placed in bins in the hold of the vessel. The usual practice is to place alternate layers of ice four to six inches in thickness and shrimp two to four inches in thickness. Except for adding ice as needed at the sides and front of the bins, the cargo is not disturbed until unloaded at the fish receiving house. In case excessive melting of ice occurs, the shrimp are removed from the bin and re-iced as described above.

This method of storing shrimp on board trawlers, although convenient from the point of view of the crew, has several inherent disadvantages. The water from the upper layers of melting ice percolating down through the mass carries bacteria from these layers which are added to the bacterial load of the lower layers (Table 3) *(3)*. Since the layers of shrimp and ice in the bins may be five feet or more in thickness, considerable crushing of shrimp in the lower layers occurs. This crushing, in addition to the high bacterial count, hastens decomposition and spoilage of the shrimp *(2)*. On arrival at the docks the shrimp are unloaded, after having been stored on the trawler for from several to as long as ten to twelve days. In this operation the

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TABLE 3

Effect of position in bin on bacterial count of some shrimp

	No. of bacteria, per gram
Whole Shrimp	
Freshly caught washed	550
Bottom layer, 4 days iced storage	190,000
Layer 3 (next to top layer), 4 days iced storage	69,000
Headed Shrimp	
Freshly caught washed	1,100
Bottom layer, 10 days iced storage	10,000,000
Layer 5 (next to top layer), 9 days iced storage	2,400

mixture of shrimp and ice is scooped into large metal cans and raised to the dock by means of a hoist. The operation of shoveling the shrimp into the buckets also contributes to further crushing, bruising, and cutting of the shrimp.

These considerations suggest that the design of the bins should be changed so as to effect three improvements: (1) water from the melting ice should be prevented from percolating through more than two or three layers of shrimp; (2) the weight of the upper layers of ice and shrimp upon those shrimp in the bottom layers of the bin should be relieved, thus decreasing the crushing of shrimp in the lower layers; (3) the handling of shrimp during the unloading operation should be minimized, thereby decreasing damage to the shrimp.

In the fish receiving house better methods of washing, and of inspecting for removal of bruised, crushed and spoiled shrimp, should be practiced. In storage the shrimp should be more thoroughly iced or refrigerated. Similar statements are pertinent to retail outlets (Table 4).

TABLE 4

Bacterial plate counts on some market samples of fresh headless gulf shrimp

	No. of bacteria, per gram
Average of composited samples from trawler	55,000
Average of 22 samples of good quality from wholesale and retail dealers	13,000,000
Average of 7 samples of spoiled shrimp from trawler	73,500,000

Frozen Shrimp

The ideal method of producing prime quality frozen shrimp is obviously to freeze them as soon as they are caught. This would mean the installation of freezing equipment on the trawlers or in lieu of this to equip a mother boat which would stay at the shrimp grounds and process the catch of several boats. Although several trawlers have installed freezing equipment the consensus is that it is not economically sound. We have shown that shrimp frozen immediately after catching are of better quality than those which were stored in ice for various periods of time *(1)*. Their quality, however, is not sufficiently improved in comparison with good frozen market shrimp to warrant an increase in price to cover the added cost of this means of processing. While it is true that a boat equipped to freeze shrimp can continue shrimping until a full load is obtained, this advantage is offset by the added expense of extra manpower needed for heading, packaging, etc. Also it has been suggested that shrimp frozen at sea on a trawler would not necessarily be of the highest quality. Refrigerated trawlers, it is contended, would buy shrimp from the ordinary shrimp fisherman at less than market price in those cases where they had remained too long at the shrimping grounds, or when excessive melting of ice had occurred and the shrimp were beginning to spoil, or where it appeared their quality would deteriorate during the time necessary to get back to port so as to make them unsalable.

Other problems connected with freezing of shrimp are the long distances that fresh shrimp are transported from ports to freezing plants, involving as it does, handling, icing, etc., with the resulting loss of quality; the use of poor moisture-vapor proof containers; and the practice of glazing. By the use of good moisture-vapor proof containers glazing can be dispensed with and the cost of shipping reduced. Storage temperatures above 0° F. (—17.8° C.) are not recommended since higher temperatures cause rapid deterioration and loss of quality *(2)*.

Black Spots

The presence of "black spots" on shrimp has been an unsolved problem of the shrimp industry for many years, and since they give an undesirable appearance to the shrimp and are associated in the public mind with spoilage, their cause and prevention is the subject of study in our laboratory. The black spots usually occur along the edges of the shell segments of the shrimp tail. When the condition is severe they are spoken of as black shrimp. Gross examination of such black shrimp, caught near the mouth of the Mississippi River, showed pronounced black bands where shell segments overlap, giving a banded or zebra appearance to the tail. The tail and head fins were black and in a majority of cases the crawling legs and to a lesser extent the swimming legs were black. Large numbers of such shrimp had the top and sides of the head infected. In those shrimp the head was soft and mushy and the chitin flexible. In fully 75 percent of the black spotted shrimp which we have studied, the chitin has been punctured or eroded away. Since the edges of the pierced portion are smooth and not jagged it is believed these holes in the shell result from chemical solution and not from mechanical injury. After attempting for more than two years without success to isolate a bacterium as the casual agent, we succeeded this past fall in isolating an organism from a typical black spot on a fresh shrimp tail. This organism, when inoculated on to nutrient shrimp agar produced black colonies and when inoculated on to sterile shrimp tails produced typical black spots. Work on this interesting problem is continuing to determine whether other microorganisms are also responsible for their development and also whether the organism is present on the shrimp as it lives in the sea or is introduced after catching. Control measures are also under investigation.

Frozen Cooked Shrimp

The popularity of frozen foods has resulted from their ease of preparation and resemblance to the fresh article. Shrimp which have been boiled and peeled before freezing would certainly be welcomed by those engaged in meal preparation, providing their quality compared favorably with the fresh product.

Our studies on frozen cooked shrimp show that cooked peeled shrimp should not be stored longer than three months, cooked unpeeled shrimp longer than six months, and for shrimp cocktail and shrimp creole the period of successful storage is much shorter, namely six weeks *(4)*. Longer periods of frozen storage will be possible when the following problems are solved: 1) development of dryness and toughness especially in ready-to-serve dishes; 2) development of off flavors caused by rancidity, which becomes more pronounced as the concentration of salt in the cooking water is increased; 3) loss of color of cocktail sauces.

Conservation

The problems of the shrimp industry as well as the industry itself will disappear unless wise and well enforced conservation measures are taken. Late this spring the writer visited the shrimp fishing area to the east of the mouth of the Mississippi River. Large numbers of females containing eggs were present in the catch along with tremendous numbers of small shrimp, less than an inch in length, which were being caught in the webbing of the nets. This continued destruction of females containing eggs and of baby shrimp will inevitably lead to the disappearance of the shrimp industry.

Summary

The problems involved in the catching, storing and handling of fresh and frozen shrimp have been discussed and modifications and changes in procedures for handling these products suggested. The cause of black spot development has been given. Suggestions have been made regarding research on the successful storage of frozen cooked shrimp and ready-to-serve dishes.

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Heat Transfer in Commercial Glass Containers During Thermal Processing[a, b]

I. S. FAGERSON and W. B. ESSELEN, JR.
Department of Food Technology, University of Massachusetts, Amherst, Massachusetts

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Some factors which influence heating rates in commercial glass containers have been investigated. Heat penetration patterns in No. 303 and 2½ size glass jars containing five percent bentonite suspensions as indicative of conduction type heating and one percent bentonite as indicative of convection type heating were studied and temperature distribution patterns in 2½ size jars are presented. The direction and distribution of convection currents in these containers during thermal processing have been studied and correlated with heat penetration data. The data obtained have been applied to the calculation of F_o values at various points in the container.

Introduction

The determination of processing times for thermally processed foods involves a consideration of a number of variables most important of which are the thermal destruction characteristics of microorganisms and the rates of heat transfer in the container of food. Mechanisms of heat transfer in tin containers have been studied by Jackson and Olson *(4)* and Jackson *(5)*, but until recently data on heating characteristics of glass-packed materials have not been as available. Merrill *(6)* has developed formulas for calculating heating rates in glass containers which take into account the factor of wall resistance and aid in extending Ball's *(1)* mathematical method for process calculation to glass containers. Townsend et al. *(9)* have compared heat penetration data for one and five percent bentonite suspensions in glass with tin containers of comparable size. They found that with one percent suspensions, jars heated more slowly in water than did cans of corresponding sizes, the effect being less pronounced with five percent suspensions particularly in the smaller containers.

The present investigation was made in order to extend our knowledge of those phases of heat transfer in commercial glass containers which are applicable to the determination of processing conditions of foods packed in these containers. Time-temperature distribution patterns in 2½ jars for materials heating by convection and conduction are presented as well as F_o distribution diagrams, F_o symbolizing the lethal value of a process as defined by Townsend et al. *(9)*. In addition, the results of a study of the distribution of convection currents in the container during thermal processing are discussed.

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[b] Contribution No. 760, Massachusetts Agricultural Experiment Station.

Experimental

Time-Temperature Distribution Patterns. The glass containers were of a type commonly used commercially for canning fruit and vegetables and are designated as No. 303 (303 x 411) and No. 2½ (401 x 414) jars with capacities of 17.0 and 28.3 fluid ounces, respectively.

Previously calibrated copper-constantan thermocouples of the type described by Townsend et al. *(9)*, connected to an automatic indicating potentiometer, were used to determine the temperatures within the containers. Five percent bentonite suspensions prepared as described by Townsend et al. *(9)* were used as the filling medium for conduction type heating. One percent suspensions prepared by dilution of the above were used as the filling medium for convection type heating. The containers were processed under water in a small vertical retort. Temperature control was provided by an automatic controller-recorder. Metal clamps of the type described by Townsend et al. *(9)* were used to hold the jar lids in place during processing. Thermocouples were introduced into the jar by two methods: one by means of packing glands soldered to the jar lids, and the other by drilling holes in the sides of the jars and inserting the thermocouples, which were fitted with rubber stoppers of proper size in the holes. The thermocouples were located as shown in Tables 1 and 2. Inasmuch as the capacity of the retort used was such that only three jars and clamps could be accommodated at one time, each jar was fitted with three thermocouples so that in the series of three containers temperature changes could be noted at the nine selected locations.

Heat penetration data for No. 303 and No. 2½ jars with one and five percent bentonite suspensions at initial temperatures (IT) of 140° and 180° F. (60° and 82° C.) respectively were obtained. In all cases the jars were processed under water at 240° F. (115.5° C.). Heat penetration data for each thermocouple location in the jars were obtained on from six to ten processing runs for each case. Retort come-up time ranges for 303 size containers of one percent bentonite were from 8 to 10 minutes and 5 to 11 minutes for initial container temperatures of 140° and 180° F., respectively; for five percent bentonite the ranges were 8 to 9 minutes and 4 to 5½ minutes for initial container temperatures of 140° and 180° F., respectively. Come up time ranges for 2½ size containers of one percent bentonite were from 8½ to 9 and 5 to 5½ minutes for initial temperatures of 140° and 180° F. respectively; for five percent suspensions the ranges were from 8 to 9 and from 5 to 5½ minutes for initial temperatures of 140° and 180° F. As there was very little variation in the results obtained in different runs, average values for the data are reported in Tables 1 and 2.

Time-temperature distribution patterns across three horizontal planes and through a vertical plane were determined for both one and five percent bentonite suspensions. Patterns across the central horizontal plane and in a plane through the verttical axis of the No. 2½ container are presented as illustrative of the data obtained (Figures 1 and 2).

Results

In the five percent bentonite suspensions, the time-temperature distribution patterns showed an initial lag period as indicated by a relatively small temperature differential between points near the center of the container as compared to the differential between the wall and a point three-quarters of an inch from the wall. Following the lag period, the temperature rose more or less uniformly from the center to the wall of the con-

TABLE 1

Average Processing Data Obtained for No. 303 Jars of Bentonite Processed at 240° F. and Using Different Initial Temperatures (IT)

Thermocouple No.	Distance from bottom of jar	Distance from wall of jar	1% Bentonite					5% Bentonite				
			IT = 140° F.		IT = 180° F.			IT = 140° F.		IT = 180° F.		
	inches	*inches*	f_h	j	f_h	j	F_o[1]	f_h	j	f_h	j	F_o[2]
1	3	½	6.8	1.14	6.8	1.00	8.53	42	1.07	44	0.93	10.67
2	2	½	7.8	1.18	7.8	1.01	8.23	49	1.05	47	1.02	9.69
3	¼	½	8.4	1.31	8.5	1.25	7.83	50	1.06	47	1.07	9.95
4	3	1	7.8	1.06	7.6	0.85	8.44	48	1.41	48	1.28	10.08
5	2	1	8.4	1.05	8.7	0.84	8.17	52	1.58	50	1.63	8.32
6	¼	1	8.3	1.43	8.4	1.16	7.93	50	1.35	47	1.33	9.22
7	3	1½	7.4	1.10	7.0	0.79	8.67	53	1.42	50	1.43	8.47
8	2	1½	7.8	1.12	8.0	0.90	8.29	54	1.67	52	1.68	8.00
9	¼	1½	8.7	1.14	8.6	1.03	8.00	47	1.38	45	1.42	9.70

[1] Based on a 37.5-minute process. [2] Based on an 82-minute process.

TABLE 2

Average Processing Data Obtained for No. 2½ Jars of Bentonite Processed at 240° F. and Using Different Initial Temperatures (IT)

Thermocouple No.	Distance from bottom of jar	Distance from wall of jar	1% Bentonite					5% Bentonite				
			IT = 140° F.		IT = 180° F.			IT = 140° F.		IT = 180° F.		
	inches	*inches*	f_h	j	f_h	j	F_o[1]	f_h	j	f_h	j	F_o[2]
1	4	¼	9.5	1.47	9.5	1.23	9.03	64	1.00	56	1.00	16.60
2	2½	¼	12.0	1.49	12.5	1.29	8.21	68	1.03	62	1.01	14.90
3	1¼	¼	12.5	1.51	14.0	1.33	6.78	69	1.17	64	1.05	14.18
4	4	1¼	9.5	1.44	10.0	1.26	9.08	71	1.13	69	1.14	11.98
5	2½	1¼	11.0	1.49	11.5	1.34	8.27	73	1.58	73	1.15	9.28
6	1¼	1¼	12.0	1.60	13.0	1.37	7.79	71	1.39	69	1.34	11.45
7	4	2	9.0	1.16	9.5	1.06	9.25	71	1.31	70	1.24	11.45
8	2½	2	11.0	1.35	11.5	1.21	8.32	74	1.82	72	1.80	8.00
9	1¼	2	11.5	1.47	13.5	1.29	8.00	70	1.53	66	1.50	11.35

[1] Based on a 45-minute process. [2] Based on a 115-minute process.

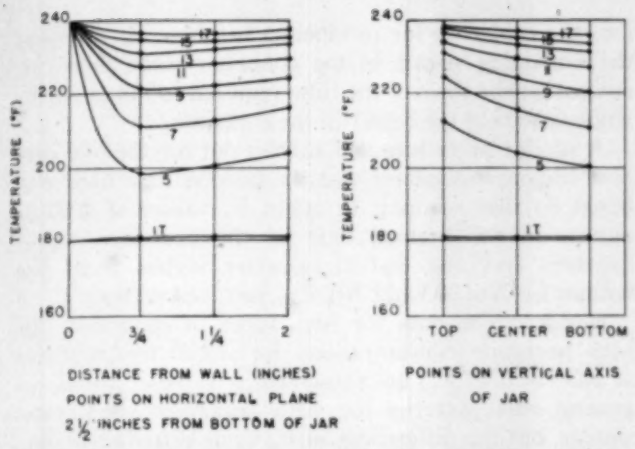

FIG. 1. Temperature distribution in No. 2½ jars at various times (in minutes) during processing: 1 percent bentonite, LT = 180° F. (82° C.).

tainer. It is interesting to note that though the metal lid of the container has a greater thermal conductivity than the glass wall this does not appear to affect significantly the characteristic pattern of simple conduction heating across the central horizontal plane which is similar in form to patterns obtained by Jackson and Olson *(4)* for five percent bentonite suspensions in cans.

In the case of the one percent bentonite suspensions (see Figure 1), the patterns obtained were of a different nature. The maximum temperature differential appears to be located in the region approximately three-quarters of an inch from the jar wall. Reference to Figure 1 indicates that the jar heats from the top downward which is in agreement with Jackson and Olson's *(4)* hypothesis that "the rising hot liquid forms a thin-walled tube adjacent to the can wall. As the hot liquid reaches the top of the can it spreads inward over the upper surface of the remaining liquid . . . the large cylinder of liquid within the rising tube is relatively quiescent. This cylinder must move down slowly as the liquid in contact with the bottom is heated and enters the rising tube, and the liquid flowing from the top of the tube replaces that at the top of the cylinder."

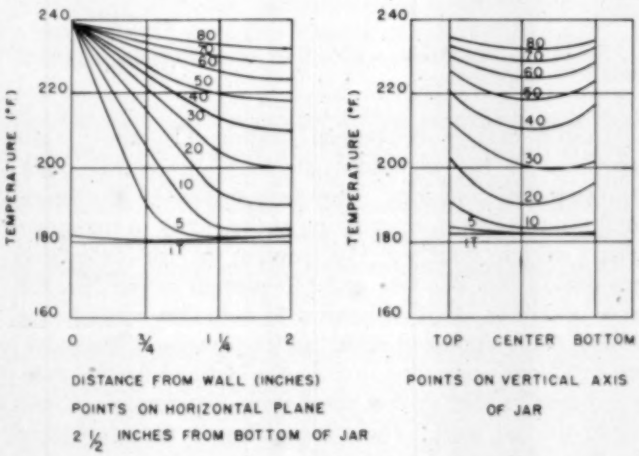

FIG. 2. Temperature distribution in No. 2½ jars at various times (in minutes) during processing: 5 percent bentonite, LT = 180° F. (82° C.).

Convection Currents

Experimental. On the basis of the above observations, further study on the nature of the convection currents seemed desirable. Currents were rendered visible by the addition of a methylene blue solution layered on the bottom of a No. 303 and No. 2½ jar filled with water. The container lids were fitted with a stuffing box and thermocouple and held with a metal clamp of the type previously mentioned. The assembly was carefully lowered into a large glass cylinder of water, the latter maintained by means of a thermostat at 100° F. (55.5° C.) above the initial temperature within the container. The distribution of the currents was correlated with the temperature in the container as measured by the thermocouple which was located with the sensitive portion three-quarters of an inch from the bottom of the container on the vertical axis of the jar. The distribution of the currents in No. 2½ jars was recorded by means of motion pictures some reproductions of which are shown in Figure 3.

Results. Under the conditions of the experiment, initial temperature of 50° F. (10° C.) and water bath temperature of 145° F. (63° C.), the currents in the jars traveled rapidly from the bottom upward along the inner surface of the container and formed a slowly descending central column within about 15 seconds after the start of the heating period (Figure 3A, 3B). Three to five minutes later, the descending central column had reached the bottom of the jar (Figure 3C). During this time, currents had started from the center of the bottom of the jar and traveled upward to about one and one-half inches from the bottom, the height attained progressively decreasing with time until after five minutes these currents were only traveling to about three-quarters of an inch from the bottom. The velocity as well as the height attained by the rising currents next to the wall of the jar progressively decreased with the time until after about 20 minutes they only rose to within about one inch of the top before descending and at the end of about 27 minutes they rose to only one-half the jar height. At this time the temperature at a point three-quarters of an inch from the bottom of the jar was about 8° F. below the water bath temperature.

F_o Distribution Patterns

F_o distribution patterns were prepared from data obtained by processing jars containing one and five percent bentonite suspensions in a steam retort under water at 240° F. (115.5° C.). Time-temperature relations were recorded until all points in the container had reached a minimum temperature of 239° F. (115° C.). When this condition was attained, the steam supply was turned off and the cooling cycle begun. Cooling was continued until all thermocouple readings in the containers had fallen to a maximum value of 200° F. (93.5° C.). F_o values at each of the nine positions in the container were then calculated using the general (graphical) method *(3)* and considering zero time as 42 percent of the retort come-up time as suggested by Ball *(1)* and Townsend et al. *(9)*. The data are included in Tables 1 and 2.

In the case of five percent suspensions, a process time was calculated to give an arbitrary F_o value of 8.00 at a position near the geometric center of the container, i. e., the cold zone for conduction heating. F_o values at the remaining points in the container were then calculated on the basis of the time required to obtain an F_o value of 8.00 at the center of the container.

A similar procedure was carried out for the one percent suspensions except that the process time used was based on that required to attain F_o values of 8.00 at points on the vertical axis of the container three-quarters and one and one-quarter inches from the bottom for No. 303 and No. 2½ jars, respectively.

Results. The data for both types of containers for both bentonite concentrations for initial temperatures of 180° F. (82° C.) are presented in Tables 1 and 2. In general, the patterns for both container sizes were similar, but the differences in F_o value distribution was more pronounced in the larger jars and the results for these containers are presented graphically in Figures 4 and 5.

In conduction type heating F_o values were at a minimum at the approximate geometric center of the container. This is in agreement with theory and confirms the generally accepted locale of the cold point. When this region had received the calculated process value, all other points were over-processed to varying degrees, the maximum occurring in the zone defined by the thermocouple located four inches from the bottom of the container and three-quarters of an inch from the wall (See Figure 4). This region received 208 percent of the calculated desired lethality in 2½ jars and 133 percent in 303 jars.

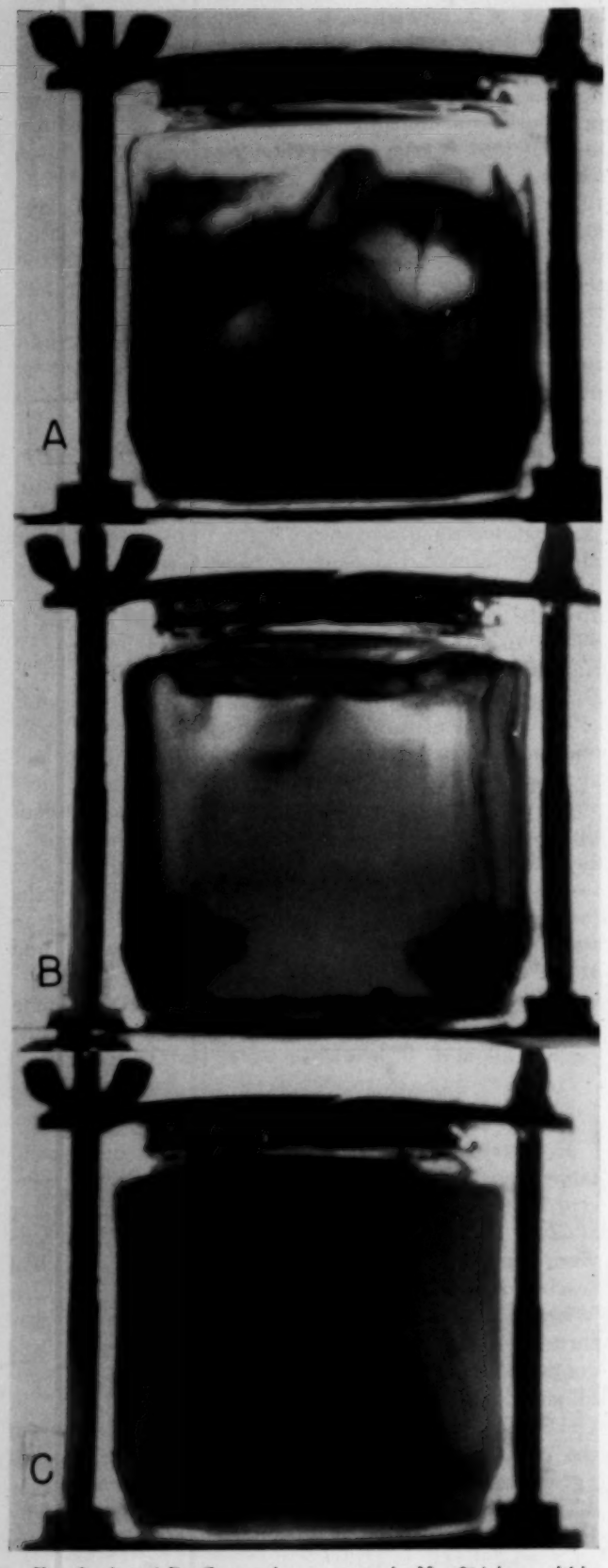

FIG. 3. A and B: Convection currents in No. 2½ jars within 15 sec. of start of heating; C: 3 to 5 min. later.

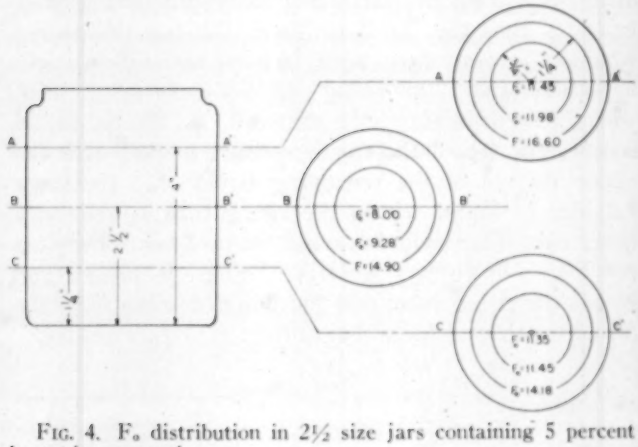

FIG. 4. F_o distribution in 2½ size jars containing 5 percent bentonite suspension.

In the case of convection heating (Figure 5), all portions of the container above a horizontal plane through the "cold zone" were over-processed, the maximum in this instance occurring at the center of the upper plane which received 116 percent of the calculated process in No. 2½ size and 110 percent in the No. 303 size container. It is of interest to note that zones in the lower plane appeared to be under-processed, the minimum values occurring in a region defined by the thermocouple located in this plane three-quarters of an inch from the jar wall. This observation is of significance in that cold zone determinations are generally based on the assumption that the critical zone is centered on the vertical axis of the container, heat penetration tests usually being carried out to ascertain the height on the

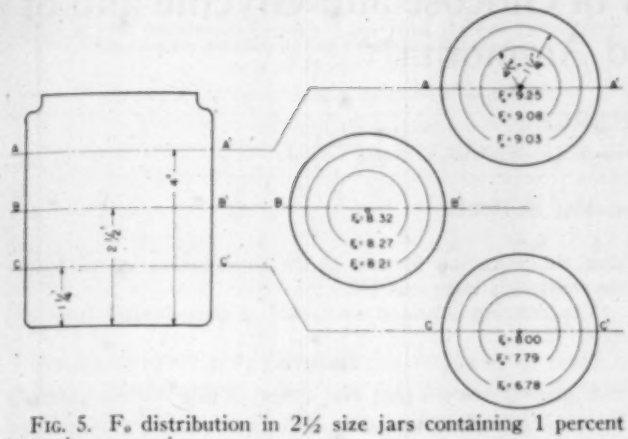

FIG. 5. F_o distribution in 2½ size jars containing 1 percent bentonite suspension.

axis where the process value is at a minimum. Since a previous study indicated that there is considerable product circulation in the container during heating, it seems reasonable to assume that microorganisms which initially are randomly distributed throughout a container of fluid media would tend to circulate with the product so they would be subjected to varying lethalities depending upon their location and velocity. Such considerations have been discussed by Stumbo *(7, 8)*.

Discussion

Though the transfer of heat through the container alone is not uniform since the metal closure has a greater thermal conductivity than glass itself, in the five percent bentonite suspensions the net effect is that such F_o values obtained near the geometric center of the container are still minimal for the jar. Hence, for heating by simple conduction, if the desired lethality is attained at this zone, all other points in the container will receive a process greater than this value.

In the case of the one percent suspensions, though the point upon which the F_o values were based, namely, the center of the lowest horizontal plane was within the usually accepted cold zone in the 303 size jars, it was about one-half inch above the usual cold zone in the No. 2½ jars. However, it is believed that this does not appreciably alter the relative values found in the container and will serve the purpose of this discussion.

It is usually assumed in making heat penetration studies in products exhibiting convection type heating that the cold point is located on the vertical axis of the container, experimental determinations being carried out to determine the point on the axis where lethal heat is at a minimum. This study indicates that the cold point is not on the axis, but closer to the jar wall. It should be pointed out, however, that microorganisms in the container do not remain stationary in the container during heating as is the case in those materials heating by conduction and it is possible that no microorganisms in the container receive as low a lethal process as is indicated by the minimal value found, since at some later time they have passed through this cold point to a region where the lethality is greater. One may speculate that a minimal F_o value on the vertical axis as usually determined represents what we may term an "average cold point." This "average cold point" may approximate the summation of lethalities received by microorganisms as they are carried by convection currents through the container, the path of the microorganisms being such that they receive a minimum heat treatment at each location. However, in calculating process times in products heating by simple convection, it appears that further consideration should be given to the occurrence of lower F_o values between the vertical axis and the wall. The practical significance of these observations in relation to actual food products which heat by convection is yet to be determined.

Summary

A study of heat transfer in 303 and 2½ size glass containers has shown that for conduction type heating as represented by five percent bentonite suspensions, temperature distribution within the container during thermal processing was similar to that found in cans.

Visual observations of convection currents in glass containers were in agreement with Jackson and Olson's theory on the mechanism of heat transfer by convection in tin cans.

F_o distribution patterns for both convection and conduction type heating are presented and show that F_o value distribution was neither uniform nor symmetrical within the container. In the case of heating by convection as represented by one percent bentonite suspensions, it is pointed out that minimal F_o values may not lie on the vertical axis as commonly assumed, but between the vertical axis and the container wall.

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Fluorescence Changes in Solutions of Glucose and Glycine and of Acetaldehyde and Ammonia[a, b]

JESSE A. PEARCE

Division of Applied Biology, National Research Laboratories, Ottawa, Canada

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Fluorescence development in glucose-glycine mixture, acetaldehyde-ammonia mixture and stored egg powder closely resemble each other. Other work has shown that a relationship exists between fluorescing substances in powdered egg and eating quality. Acetaldehyde-ammonia mixture being a simpler molecular system should make studies of these fluorescing substances in foodstuffs easier.

Work in these laboratories *(7, 8)* and elsewhere *(1)* has shown a close relation between the fluorescing substances in egg powders and the eating quality of the product. Since fluorescence development in foodstuffs is not confined to egg powder *(4)*, numerous studies have been made of this and of an associated phenomenon, "browning." Difficulties in determining the nature of the reaction and of the reaction products in foodstuffs *(2, 3, 6)* have led to studies in model systems, one of which *(5)* showed that fluorescence development in glucose-glycine mixtures resembled that in stored egg powder. Since this system is also complicated, it seemed desirable to examine fluorescence changes in model systems of simpler molecules. No reports on fluorescence changes in these systems could be found in the literature. The system acetaldehyde-ammonia was chosen because formaldehyde holds an anomalous position in the aldehyde series. This paper describes the effect of concentration of reactants and of temperature on the rate of fluorescence development in solutions of glucose and glycine, and of acetaldehyde and ammonia.

Materials and Methods

Mallinckrodt's anhydrous glucose (analytical reagent grade), Eastman's ammonia-free glycine, General Chemical's best grade of acetaldehyde and Nichols' reagent grade ammonia were used without further purification. The water was demineralized in a Barnstead unit and had a pH of 5.8.

In one phase of the study, solutions of two g. of glucose, one g. of glycine and 30 ml. of water were used to examine the effects of pH levels from 4 to 8 on fluorescence development. To keep the system as simple as possible, the pH was adjusted with hydrochloric acid and sodium hydroxide. To mask any effects attributable to trace amounts of sodium or chloride ions, 0.3 g. of sodium chloride was added to each solution; and to evaluate the effects of sodium chloride, solutions were stored at pH 5.8 with and without added salt.

Fluorescence values were determined by diluting the reacting mixture appropriately with water and measuring the fluorescence of the resulting solution in a Coleman photofluorometer, using the B_1 filter which transmits activating light in the region of 365 millimicrons and the PC-1 filter which transmits fluorescent light above 400 millicrons *(6)*. As in previous studies, measurements were continued until a fixed fluorescence value was obtained. For part of the study, in which the rate of change was slow, this value was 50 units on the fluorometer; for the rest of the study, this value was 100.

The reacting solutions were held at temperatures from 27° to 93° C.

Results

Figure 1 shows that the shape of the curves relating fluorescence development and time was the same for stored egg powder *(9)*, for solutions of glucose and glycine, and for solutions of acetaldehyde and ammonia. The effect of different concentrations of glucose and glycine on the time required to attain a fluorescence value of 50 units is summarized in Table 1. (For this phase of the study, the reacting mixture was diluted 1:125 before making the fluorescence reading.) The table shows that decreasing the concentration of either component increased the time required to attain a fluorescence value of 50 but that decreasing the concentration of glycine caused a greater increase in time than was caused by an equivalent decrease in glucose. Similar behaviour was noted at all temperatures studied (60°, 71°, 82°, and 93° C.).

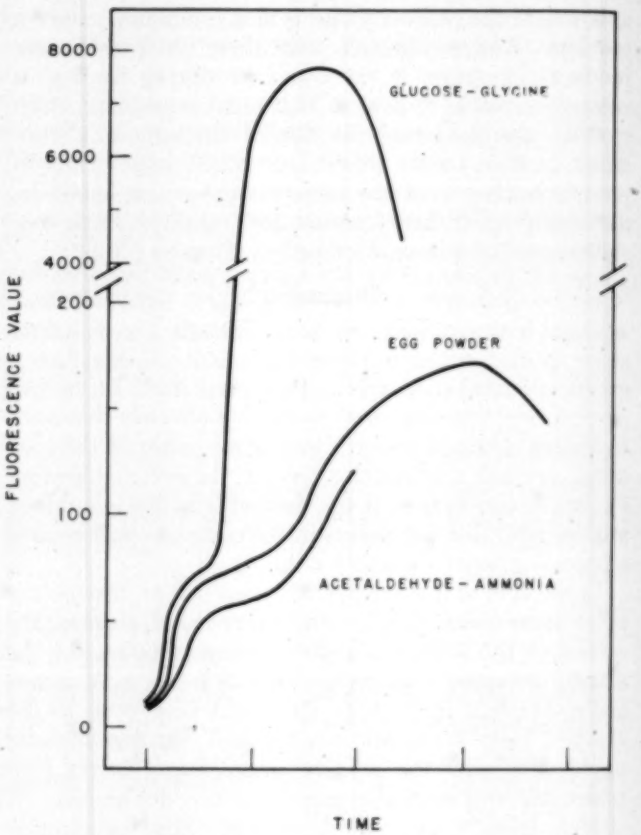

FIG. 1. Similarity in curves showing increase with time in fluorescence values of egg powder, glucose-glycine solution, and acetaldehyde-ammonia solution.

[a] Issued as Paper No. 248 of the Canadian Committee on Food Preservation and as N. R. C. No. 2217.

[b] Presented before the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 24, 1950.

TABLE 1

Effect of concentrations of glucose and glycine on the time (min./1000) required for solutions of both to attain a fluorescence value of 50 at 27° C.

(Diluted 1:125, before making fluorescence reading)

Glucose, *M*/1	Glycine, *M*/1						
	1.0	0.50	0.25	0.10	0.050	0.025	0.0125
1.0	2	9	28	50	....	....	....
0.50	7	18	....	....	....	....	....
0.25	13	....	....	....	....	....	....
0.10	16	....	....	71	224	355	....
0.050	....	....	....	141	....	....	562
0.025	....	....	....	224	....	....	....
0.0125	....	....	....	....	355	....	....

As noted previously *(5)* the time required to reach a definite fluorescence value can be considered as the reciprocal of the rate of reaction, and apparent heats of activation can be calculated. The average heat of activation over the temperature range from 60° to 93° C. for all combinations of concentrations given in Table 1 was 24 kgm.-cal. (standard deviation of the mean, ± 3 kgm.-cal.) and there was no evidence of change in this value with a change in concentration of the components (Figure 2). This value approximates those found in egg powders *(5)*.

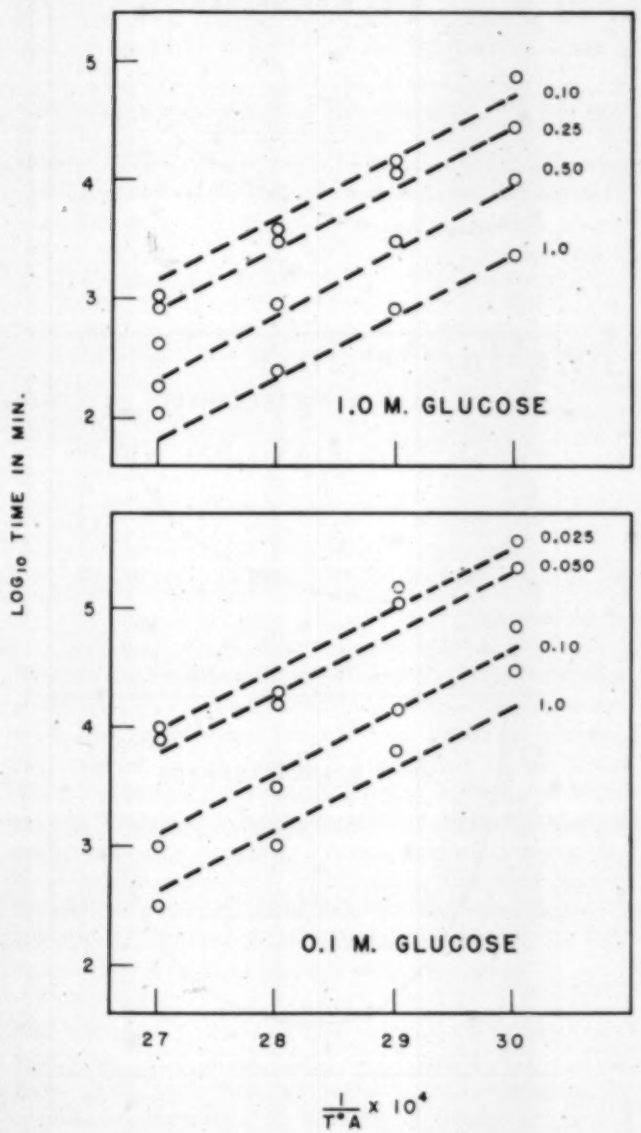

FIG. 2. Effect of concentration and temperature on the time (min.) required for glucose-glycine solutions to attain a fluorescence value of 50 units. Labels indicate molar concentrations of glycine.

The effect of pH on the rate of fluorescence development in glucose-glycine solutions was determined in the temperature range of 27° to 60° C. (Figure 3). In this phase of the study the reacting mixture was diluted 3:50 before fluorescence measurements were made. The times recorded are those required for the diluted solution to attain a fluorescence reading of 100 units. Increasing the pH of the reacting mixture from 4 to 6 caused only a negligible decrease in the time required to reach a fluorescence value of 100 but further increases in pH caused a marked reduction in time, i.e. a marked increase in the rate of fluorescence development.

Fluorescence measurements were made directly on reacting mixtures of ammonia and acetaldehyde and the times recorded are those required for this system to attain a fluorescence value of 100 units. An increase in temperature from 27° to 71° C. caused a decrease in the time required for these solutions to attain a value of 100 (Figure 4). A further increase to 93° C. caused no further decrease in time. The results obtained at 93° C. differed only in minor respects from those obtained at 71° C.

Figure 4 shows that at all temperatures studied the rate of fluorescence development was most rapid when the solutions contained between 0.0625 and 0.125 moles per liter of ammonia. At the two lower temperatures

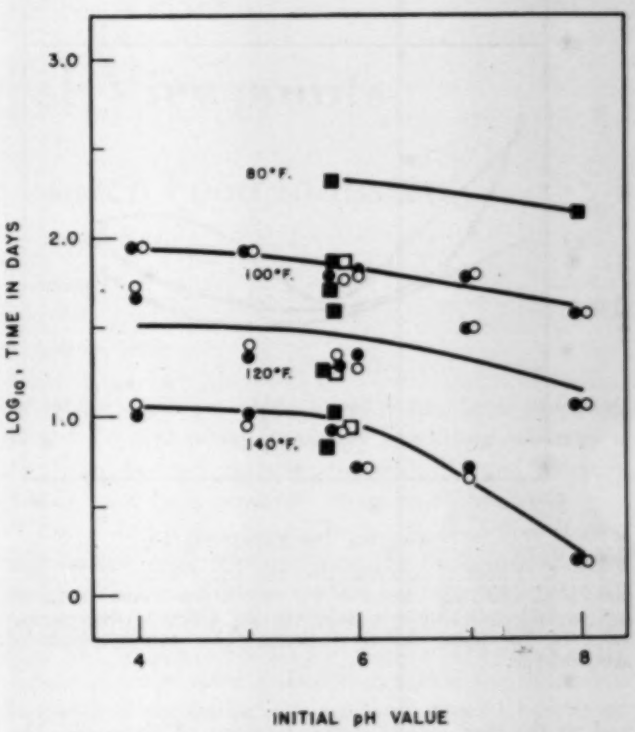

FIG. 3. Effect of temperatures of 27°, 38°, 49° and 60° C. (80°, 100°, 120° and 140° F.) and pH on the time (days) required for glucose-glycine solutions to attain a fluorescence value of 100 units.

Circles: 2 g. of glucose, 1 g. of glycine, 0.3 g. of sodium chloride and 30 ml. water. Squares: 2 g. of glucose, 1 g. of glycine, and 30 ml. water. Shaded circles or squares: Fluorescence measured without adjusting pH. Shaded squares or circles: Fluorescence measured after adjusting reacting mixture to pH 5.8.

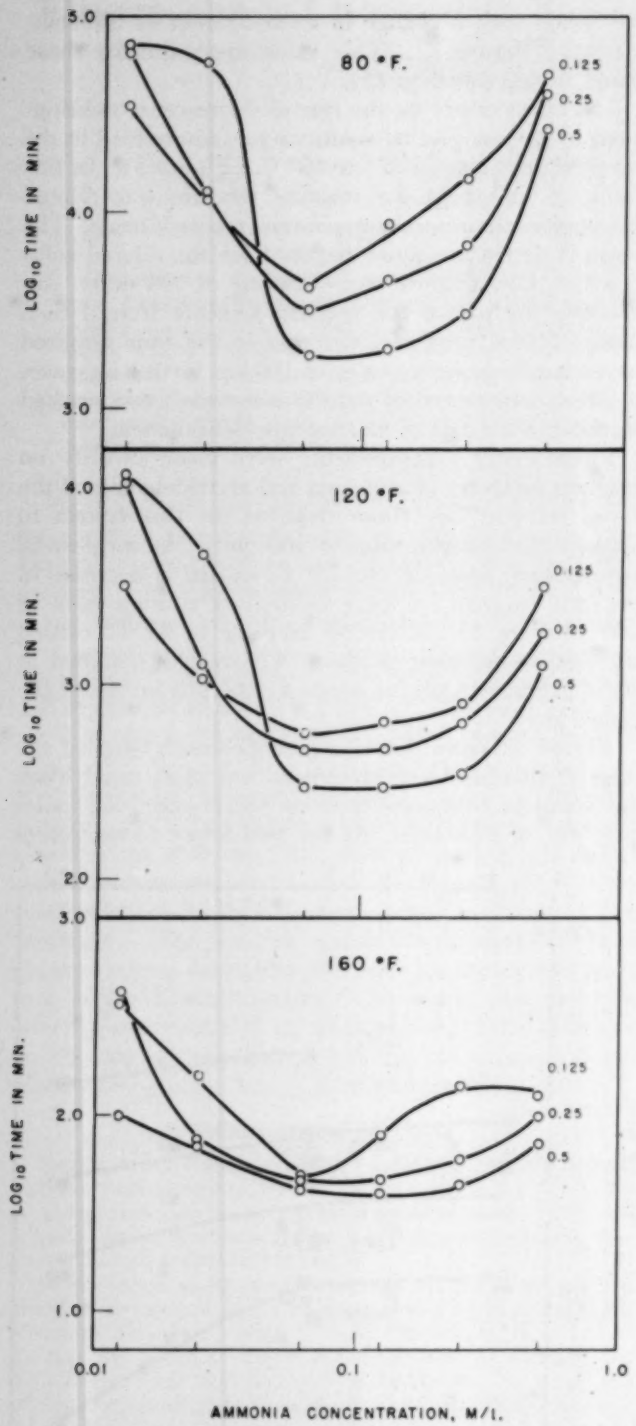

FIG. 4. Effect of concentration and temperature of 27°, 49° and 71° C. (80°, 120° and 160° F.) on the time (min.) required for acetaldehyde-ammonia solutions to attain a fluorescence value of 100 units. Labels indicate molar concentrations of acetaldehyde.

and at the two lowest concentrations of ammonia, the rate of fluorescence development was inversely proportional to the concentration of acetaldehyde.

The increase in rate with increase in temperature from 27° to 71° C. was examined by calculation of apparent heats of activation for fluorescence development. For solutions with acetaldehyde-ammonia concentrations (moles per liter) of 0.50:0.025, 0.50:0.0125, and 0.25:0.0125, there was evidence of curvature in the line relating logarithm of time to attain a fluorescence value of 100 units and the reciprocal of the absolute temperature. When this was disregarded, the apparent heat of activation for fluorescence development became a function of the acetaldehyde and ammonia concentrations as shown in Figure 5. For aldehyde concentrations of 0.125, 0.25 and 0.50 M, the apparent activation energy was at a minimum at respective ammonia concentrations of approximately 0.025, 0.040 and 0.080 *M*. The values for the apparent heat of activation, calculated for temperatures from 27° to 71° C., ranged from 19 to 33 kgm.-cal., which is approximately the same as values noted for egg powder and for mixtures of glucose and glycine *(5)*, but upon which the effects attributable to concentration of acetaldehyde and ammonia are superimposed.

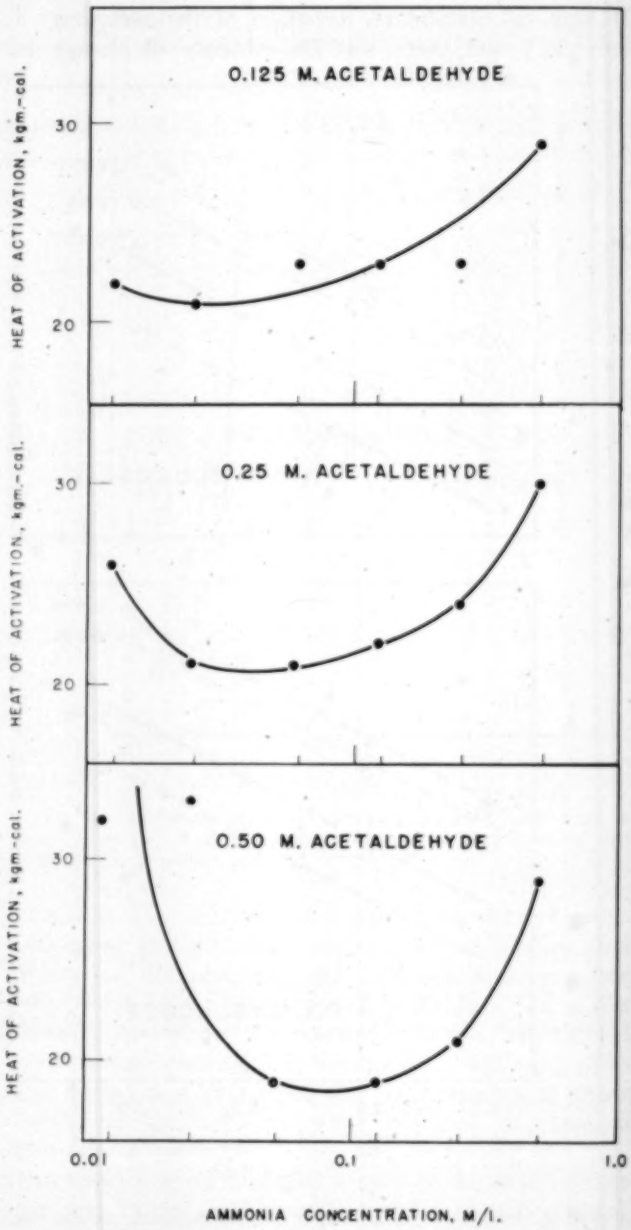

FIG. 5. Change with concentration in apparent heat of activation for fluorescence development in solutions of acetaldehyde-ammonia.

Since the acetaldehyde-ammonia system developed fluorescing materials in a manner similar to that of glucose-glycine mixtures and to that of stored egg-powder, it was concluded that a comprehensive study of the simplest system would be a helpful prerequisite to studies of the complicated systems that exist in foodstuffs.

Summary

Solutions of acetaldehyde and ammonia held at temperatures from 27° to 93° C. increased in fluorescing substances in a manner similar to that noted in solutions of glucose and glycine and to that noted in stored egg powders. Decreasing the concentration of glycine reduced the rate of fluorescence development more markedly than an equal reduction in the concentration of glucose. On the other hand, fluorescence development was more rapid at ammonia concentrations of 0.0625 to 0.125 *M* than at higher or lower concentrations. At low ammonia concentrations fluorescence developed most rapidly in solutions containing 0.125 *M* acetaldehyde and least rapidly in solutions containing 0.5 *M*. The apparent heat of activation for fluorescence development in solutions of glucose and glycine was not affected by concentration of the reactants and averaged 24 kgm.-cal., which approximates that for stored egg powder. The apparent heat of activation for fluorescence development in solutions of acetaldehyde and ammonia varied from 19 to 33 kgm.-cal. and was high at ammonia concentrations of 0.5 and 0.0125 *M* and low in the range of concentrations from 0.025 to 0.080 *M*.

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Industrial and Legal Viewpoints

Sanitation Practices in the Frozen Food Industry[a]

K. G. DYKSTRA and S. E. SMITH

Birds Eye-Snider Division, General Foods Corporation, Albion, New York

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With the evolution of the frozen food industry, food processors have been confronted with many new and challenging problems. One of these problems which is ever present is the increased importance of sanitation. The term sanitation as applied today includes such factors as lighting, ventilation, rodent and fly control, safety of water supplies, lavatory facilities, waste disposal, and many others. In addition, the term may be defined as meaning cleanliness or the reduction to a workable minimum of foreign matter within the food processing plant or within the product.

Proper sanitation is required of all food processors not only from a moral or ethical point of view but also legally so. The Food, Drug & Cosmetic Act of 1938 states in Section 402 (a) that . . . "A food shall be deemed adulterated if it consists in whole or part of any filthy, putrid, or decomposed substance, or if it is otherwise unfit for food; or if it has been prepared, packed or held under insanitary conditions whereby it may have become contaminated with filth; or whereby it may have been rendered injurious to health."

Those well chosen words in our Federal law place a tremendous economic responsibility on people directly responsible for sanitary conditions in their plants. All persons responsible for sanitation of food plants should read this section of the act and consider the all-inclusive nature of these words,—and then tackle the individual problems of sanitation with renewed vigor. There is no greater or more potent agent to stir activity than a potential economic loss or gain.

The field of sanitation is a wide one and each plant or product has its own particular sanitary problems. It is not within the scope of this discussion to deal with all of the problems of a sanitary nature which the frozen food processor may face. This talk will be limited to the phases of freezing plant sanitation which have direct

[a] Presented at the Tenth Annual I. F. T. Convention, Chicago, Illinois, May 24, 1950.

bearing on the sanitary condition of the frozen product. As we proceed in this discussion, it may appear that we digress into the field of quality control, but the dividing line between sanitation and quality control is narrow and obscure.

When one considers the wide variety, the diverse nature, and the large volume of foods which are packaged and sold in the frozen state, the problems of sanitation become complicated and very specific. Quite obviously then, it is not possible to establish a single code of sanitary practices which will be applicable to all plants processing foods for freezing. The problems of achieving a satisfactory degree of cleanliness in a vegetable freezing plant are not necessarily the same as those which will be encountered in a plant producing frozen concentrated orange juice. Each plant or product must be considered separately, the individual problems determined, and the answers formulated accordingly.

There are, however, many sanitation problems and practices peculiar to the frozen food industry which have been adopted generally by the frozen food industry but may not be used extensively in other food industries. Most of the fruits and vegetables destined for freezing are packaged during the warm months of the year. The temperature during these months is usually between 70° F. and 100° F. These temperatures are most favorable for the rapid spoilage of raw material as a result of abnormal growth of micro-organisms or abnormal enzymatic activity. The micro-organism populations of most freshly harvested fruits or vegetables are initially high. Now, what can sanitarians do to avoid losses or deterioration? Here are a few points which are their responsibility, at least jointly with quality control personnel to investigate, and if necessary, rectify.

1. What is the condition of lug boxes, crates, hampers, or other containers used in the handling of raw material from field to plant? Many plants use such containers without inspection or cleaning except to toss them away when they have become so thoroughly rotted that they break under a load of raw material. Such containers, usually porous in nature, after several reuses are excellent sources of contamination of raw material. What can one do about it? Washing between uses, preferably with a detergent, is helpful. Painting to render surfaces non-porous and washing between uses is much better. Inexpensive dips containing germicides having latent action are available. In other words, keep containers used for the transfer and storage of raw material clean, and the hazards of mold, rot, or decay showing up in finished product will be considerably reduced.
2. Quite often the harvesting of raw material calls for special equipment. The lack of the usual cleanup facilities in the field is sometimes used as an excuse to condone operating with dirty equipment. Take, for example, pea viners. If these are operated without an attempt at cleanliness, you can rest assured that each pea (the tender ones in particular) is receiving ample contamination in the form of micro-organisms from old or decayed peas or pea juice. It takes daily attention and hard work to keep a viner clean.
3. What about the length of time of holding raw material and the temperatures at which it is held? We are all aware of the fact that immediate processing of raw material is best, but we are all realistic enough to know this is practically impossible and that the recent trend is actually toward casting farther afield for raw material. This in turn means that the handling of material in a satisfactory manner to the processing line becomes more and more critical. Therefore, if time is lengthened, the control of temperatures becomes important. The practice of "precooling" has become important in the frozen food industry. However, indiscriminate use of precooling may lead one into serious difficulties. Many fruits and vegetables cannot be immersed or sprayed with cold water without causing undesirable results. Also any precooling equipment must be kept scrupulously clean or it will serve merely as a further contaminator. Proper application of pre-cooling requires a knowledge of (a) method for best application of cold (b) which raw materials can be cooled and held, and (c) at what temperatures and how long it is safe to hold after cooling.

Proper sanitation practices directed toward harvesting or transportation facilities are often lacking. It is most desirable to review such practices in this light and give the processing plant a head-start in producing the quality.

Now, moving into the area of processing of frozen foods, the sanitation requirements are, in general, very much like those in the processing of any moist food products. There are, however, several specific sanitation requirements which we feel are peculiar to the frozen food industry. First of all, let us state that in the processing of frozen fruits and vegetables, or for that matter, any frozen product, the final product should be clean physically, chemically, and bacteriologically.

By physical cleanliness, we mean freedom from adhering dirt, debris, or other matter which normally are observable by the human eye. By chemical cleanliness, we mean freedom from various chemical substances which may or may not be harmful, such as substances like detergents, germicides, spray residues, various scale deposits, and possibly various greases and oils. These may or may not be visible to the human eye. By bacteriological cleanliness is meant freedom from relatively excessive numbers of bacteria, yeasts, and molds.

Physical cleanliness can best be achieved through the use of mechanical devices such as washers, sprayers, shakers, inspection belts, and the like. It is not within the realm of this discussion to cover specifically the types of equipment necessary for producing the various frozen products. A degree of physical cleanliness acceptable to the public or which will conform to various standards should be set up in each operation.

Cleanliness in a chemical sence may require a different approach by the plant personnel. For example, the material being processed may contain certain spray

residues which must be reduced by plant processes to a minimum level. This may require special equipment or special treatments with a careful quality control check to assure that at all times the residue is below the maximum levels permissible. For example, in the processing of apples, it is often necessary to use an acid rinse for the removal of certain metallic spray residues. Naturally, caution must be observed in the application of chemicals used around and about the plant for germicidal or insecticidal action or for cleansing purposes. If such residues are left on equipment when the equipment is out of use, all contact parts should be rinsed with fresh water before being put into use. The application of such special chemicals should be restricted and left in charge of individuals who are adequately trained.

Finally, cleanliness in a bacteriological sense means that the product, when finally processed, shall not contain total bacterial populations above those reasonable and to be expected in any given type of product. To expand this thought further, it means that the food is processed in plant equipment which has been cleaned in such a way that it is free from relatively large amounts of bacteria or slime mold growth, which, if present, would find its way with the product into the finished package. The writers are concerned lest the wrong interpretations be placed on the importance of the total bacterial populations of frozen foods. The use of the bacterial count has become an important tool for the frozen food processor in determining the sanitary condition of his plant. Therefore, we feel that it is important to continue the use of this tool, but we also believe that great care must be exercised in the interpretation of the results of such total counts. It would be well to digress for just one moment and mention our present thinking regarding total bacterial counts. First of all, there is no reliable evidence that total bacterial populations below the levels responsible for readily observable fermentation or putrefaction will lower the quality or wholesomeness of the food product. It is presently believed that the presence of bacteria within reasonable limits is no indication that fermentation or decomposition exists in the product upon which these bacteria were found. Secondly, there is no evidence to indicate that the levels of bacterial populations usually found in frozen foods constitute any health hazards to consumer. In other words, there has yet been no recorded instance of either food poisoning or other health impairment directly traceable to consumption of frozen foods.

These statements must not be interpreted to indicate that frozen food packers should or will tolerate excessively high bacterial populations in food products. Rather, every effort should be made, and at the present time, every effort is made by responsible packers to keep the bacterial populations at the lowest minimum level consistent with efficient plant operation and practical sanitation control. These statements are made in order to indicate what present significance is placed on total bacterial counts in frozen foods. It is our premise that these total counts should be used solely as an index of the sanitary condition of the plants producing the food products. Our studies have shown that there is a very reliable relationship between the degree of sanitation and cleanliness exercised and total counts of bacteria in a given frozen food product.

Just a few words now about the application of such total bacteria counts in the processing of frozen foods. As a routine check, total counts should be taken on frozen foods several times daily but at least twice or three times every day. A good rule to follow is to select one sample for bacteriological assay early in the day, one sample approximately at mid-day, and one sample toward the end of the day. Improper or spotty cleanup practices will invariably show relatively high counts early in the day, with a tapering off during mid-day and late-day. However, if there is no routine of cleanup continuously throughout the day, rise in total counts will occur towards the end of the day. The total count can be used advantageously for line checking and thereby determine at which points the severest bacterial contamination occurs.

Individuals responsible for sanitation are urged to run line checks occasionally at the beginning of the season to become familiar with the behavior of plant equipment and to learn where might be the troublesome spots. This type of knowledge beforehand will certainly aid in setting up the routine for cleanup as well as aid you in deciding what to do when there is a tendency for total counts to creep into the upper levels. A comprehensive series of studies in which line checks were made routinely over a series of plants producing frozen vegetables (principally peas, corn, spinach, green beans, succotash, and mixed vegetables) has definitely indicated certain types of equipment to be troublesome sources of contamination. As a general rule, practically all types of equipment which convey or handle products in a dry or partially dry state are trouble makers. Gooseneck elevators, inspection belts, hoppers, and fillers are always potential sources of bacterial buildup. Much of this equipment is difficult to maintain in a clean state because of hidden crevices and difficult areas in which to apply water or detergent solutions necessary for proper cleaning. In most pea processing plants, elevators transporting peas to quality graders or gravity separators are troublesome. The upper ends of these elevators are usually partially blocked by the gravity separators and it is very difficult to clean them properly. Once this difficulty is indicated, proper cleanup measures can be developed.

In vegetable processing in particular, the lowest counts will always be found immediately after blanching. This low count theoretically should be maintained throughout subsequent operations if control of sanitation was absolute. However, this is not the case and invariably there will be a bacterial buildup due to pickup of bacteria from subsequent handling equipment. It is a challenging goal to achieve total counts equivalent to those obtained on the vegetable directly out of the blanchers.

It might be well to note methods of plant cleanup and methods of maintenance of proper sanitation in processing equipment. The specific procedures required will vary from plant to plant and with different products. However, there are certain basic principles involved which should be followed. First of all, whatever